SEWAGE WORKS JOURNAL

VOL. XI MARCH, 1939 NO. 1

Special Features

Annual Report of Research Committee

Activated Sludge Research—Ruchhoft—Heukelekian

Sewer Ventilation at Los Angeles—Studley

Tallmans Island Works—Liebmann and Fort

Treatment of Brewery Wastes—Bushee

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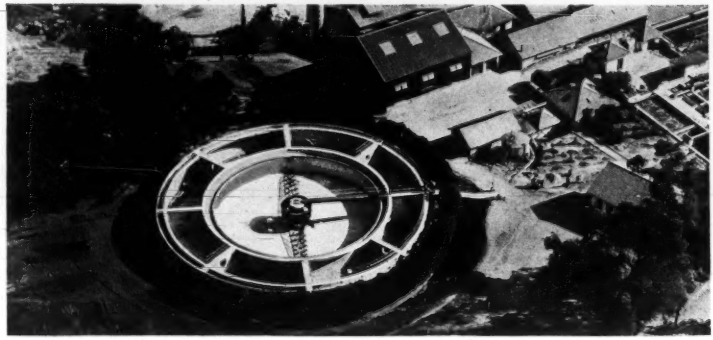

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Acknowledgment—L. J. Wolohan, Ch. Chem., Dearborn Sewage Treatment Plant

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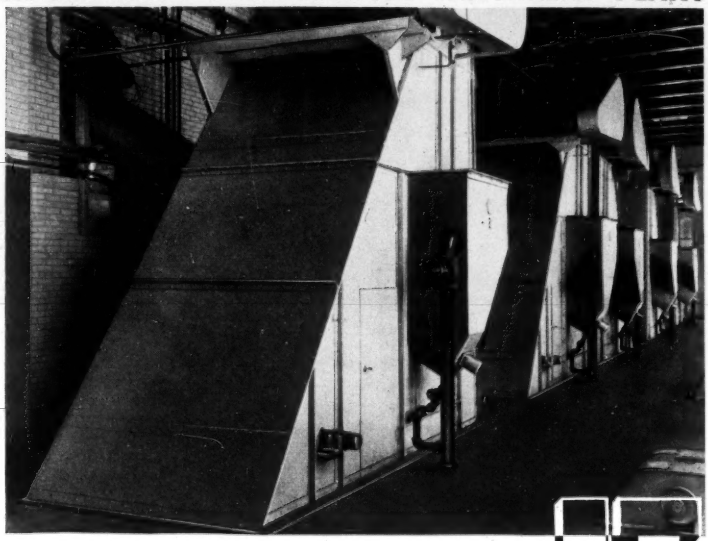

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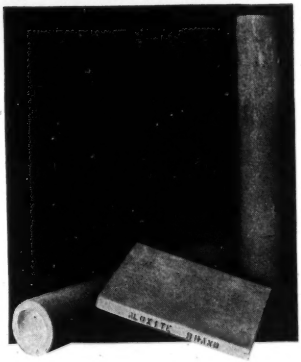

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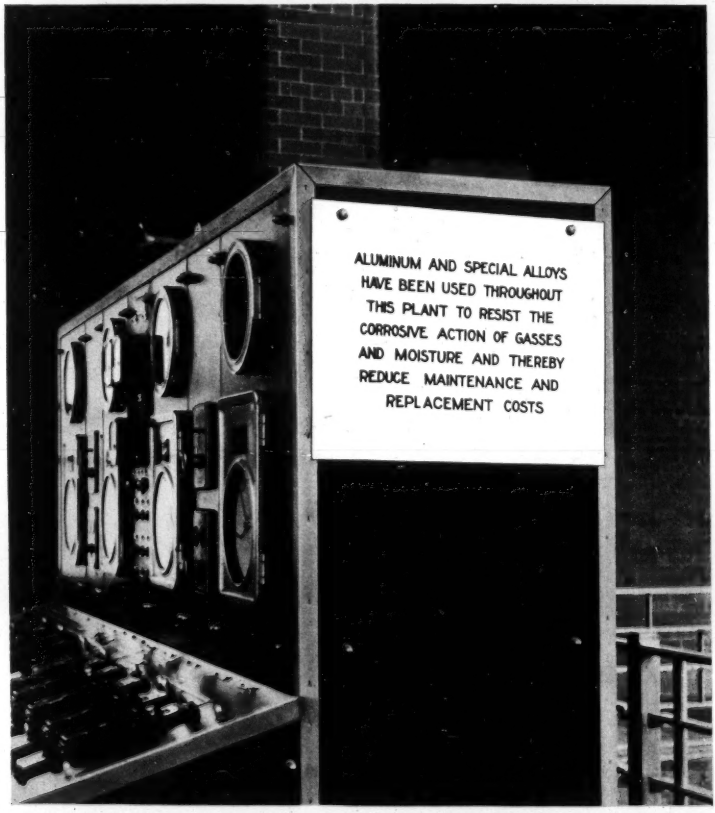

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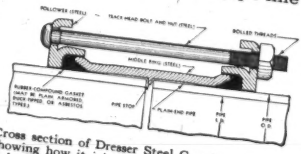

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Sewage Research:

Research in Sewage Chemistry, Sewage and Waste Treatment and Stream Pollution. A Critical Review of the Literature of 1939. By W. Rudolfs, *Chairman*, T. R. Camp, G. P. Edwards, H. A. Faber, H. F. Gray, H. W. Gehm, F. W. Gilcreas, G. E. Griffin, H. Heukelekian, R. W. Kehr, E. W. Moore and S. I. Zack 159

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Sewage Research

RESEARCH IN SEWAGE CHEMISTRY, SEWAGE AND WASTE TREATMENT AND STREAM POLLUTION

A CRITICAL REVIEW OF THE LITERATURE OF 1938

By W. Rudolfs, *Chairman*, T. R. Camp, G. P. Edwards, H. A. Faber, H. F. Gray, H. W. Gehm, F. W. Gilcreas, G. E. Griffin, H. Heukelekian, R. W. Kehr, E. W. Moore and S. I. Zack

Committee on Research, Federation of Sewage Works Associations

Chemistry and Biology

From year to year the amount of fundamental research and experimentation increases, but in many instances does not keep pace with the rapid growth of the field. Nevertheless, during the year a number of individual studies have been published which throw new and more light on the various theories, processes and procedures. In the problem of stream pollution, trade waste treatment comes more and more to the fore; not because trade waste treatment is progressing at a greater rate than sewage treatment, but because with the gradual cleaning up of sewage pollution, the problem of industrial waste pollution and its treatment stands out. For this reason the section on trade wastes has been expanded with the hope that the information will stimulate more experimental work and indicate the proper place of trade waste treatment in the whole problem of cleaner streams.

ZoBell (189) has nearly one hundred new species of bacteria characterized which grow in nutrient seawater media but not in corresponding fresh water media. The paucity of bacteria in seawater is attributed primarily to the lack of surface-active solids, which seem to be requisite to the multiplication of bacteria in dilute nutrient solutions.

It has been known for some time that the bacterial population of stored lake water is many times greater than that found in the lake itself. Increasing the area of solid surface per given volume of lake water was found by growth curve studies (158) to increase the number of bacteria in stored water; this supports ZoBell's results with ocean water studies. To determine if accumulation of organic matter upon the surfaces might be the mechanism of surface effect, a method was developed based upon oxidation of the organic matter with a sulfuric acid-potassium dichromate reagent.

The accumulation was detected upon slides sterilized and suspended in sterile lake water, showing that accumulation is independent of and precedes bacterial growth. It would seem then that surfaces by accumulation provide a suitable concentration of nutrient material for

greater bacterial development; and that although there is sufficient nutrient material in lake water for greater numbers of bacteria than are found naturally, the low concentration of this nutrient material is one of the important factors controlling the growth of bacteria in the open lake. ZoBell (190) finds that although the oxygen content of seawater is a factor which influences the activity of bacteria, it does not account for the denser bacterial population which appears in samples as compared with the original body of water. Solid surfaces are necessary for a holdfast. These findings fit in nicely with the newer studies on activated sludge discussed elsewhere in this review.

For years it has been known that phenols are readily destroyed by bacteria. It has been suggested that there must exist a definite physiological group of bacteria that is intimately connected with the destruction of phenols. It has now been suggested (23) that this should be extended to indophenols. The first step in the decomposition of the indole present in sewage in trickling filters, namely oxidation of indole to indoxyl or indogotin, is by a minor group of organisms, the Cocci.

Berl and Koerber (14) isolated a cellulose-fermenting bacillus from horsedung which decomposed about 70 per cent of the cellulose with the production of volatile and non-volatile acids and alcohol.

A new theory, or rather expansion of a theory regarding coagulation, is propounded by Ostwald (129). The question is raised as to what actually happens during the coagulation of a hydrophobic sol by neutral salts. The answer is: the coagulating forces seem to be the same as the inter-ionic attraction forces between ions of the dispersed medium. This results from the fact that the coefficient of activity, the measure of these forces, also plays a predominant role in coagulation. It may not be that the entire mechanism is as simple as the procedure looks. The new theory is not contrary to the attempts to evaluate the role played by the double layer between the dispersed part and the dispersion medium. The difference is that the double layer is looked upon as an interposed apparatus of the dispersion medium and not as the coagulating motor itself. The dispersion medium brings about the coagulation and not the double layer. The author states "It is the arm that hits and not the cane."

Sewage and effluents have been used for agricultural purposes for many years. It appears that the sewage and sludge contains various growth promoting substances, which may be valuable when the materials are used for irrigation, soil building or fertilizer (141) (142).

Methods and Laboratory Procedures

During the past year there have been few reports published of studies concerned with improvements in existing laboratory methods or the development of new procedures for the examination of sewage.

Little information is available concerning the viscosity of sewage sludges and its effect on friction losses. Hatfield (67), studying the viscosity or pseudo-plastic properties of sludge, finds that the apparent

viscosity decreases as the rate of shear and shearing stress increases. When the sludge is stirred, shaken or violently mixed the viscosity decreases. The sludge moves with increasing difficulty when the percentage solids increase.

Bloodgood (17) (18) has described in detail the construction of a machine which will determine sludge activity. He defines sludge activity as the rate of oxygen consumption by the activated sludge plus sewage minus the consumption by the sludge alone, all measured in parts per million per hour. For the Indianapolis plant, best results are obtained when the sludge activity is between 70 and 100 p.p.m. per hour, based on tests using a sludge with a concentration of 0.5 per cent solids and a synthetic sewage.

Although the methods for the determination of dissolved oxygen in water and sewage have been the source of much investigation, Ruchhoft (136) and others have developed the technique further by the use of sodium azide for the elimination of nitrite interference in the Winkler method. Thus preliminary oxidation by potassium permanganate is not required and the total time for conducting the test is correspondingly shortened. Since the sodium azide is not affected by organic matter, higher oxygen concentrations more comparable with the actual values are determined by this modified procedure.

Payne (131) came to the conclusion that standard lactose broth was more suitable for the detection of *Bact. coli* than the modified Eijkman procedure for the examination of oysters, clams and shellfish growing waters. The Eijkman test inhibited the growth of some strains of *Bact. coli* and failed to eliminate some non-coli member of coli-aerogenes group.

According to Glangeand (52) in the Girond Estuary there are four types of variations in the suspended matter: (1) instantaneous ones due to whirlpools; (2) daily ones caused by the sea; (3) irregular ones due to floods; and (4) seasonal variations.

Since the Collet bottle gives only instantaneous values, it was decided to provide an apparatus which would collect the suspended matter in 200 liters of water taken from a known depth during a 10-minute period. The water is pumped from the river at fixed depth and emptied into a funnel, from here it passes through a series of four cone-shaped cylinders of increasing diameter, and is finally discharged in a large cylinder. In this last cylinder are found only the very fine particles and colloids. After a period of 24 hours, the sediment is removed, filtered, dried and weighed.

A diagram of the apparatus is given together with some figures comparing results obtained by use of a Collet bottle and by use of the new apparatus.

Sedimentation

The model studies by Hubbell (84) (85) of the proposed grit chambers and later of the settling tanks for the Detroit, Michigan, sewage treatment project appear to be the outstanding accomplishments in

the field of sedimentation during the past year. In both these studies dyes were used effectively to study the hydraulic characteristics of the proposed units. Small scale models were constructed and were operated in accordance with Froude's law.

The grit chamber model (84) was built to a scale of 1:15 to represent a prototype 16 ft. wide by 16 ft. deep and 100 ft. long with a rack at the inlet end. Coloring matter moved with an approximately vertical front through the chamber, the first color passing in 74 per cent of the theoretical detention period, the center of mass in about 90 per cent and the last color in 130 per cent of the theoretical time. The excellent flow distribution was attributed to the presence of the rack at the inlet end. In order to study grit removal in the model an unsuccessful effort was made to simulate the grit with very fine quartz sand.

Subsequent field tests on grit removal were made by Hubbell at the existing grit chambers at Dearborn and Grand Rapids. At each of these plants, one chamber was taken out of service, cleaned and equipped with suitable baffles and weirs to control the depth and velocity at desired values. Sewage was then allowed to flow through the chamber and after flow became steady, several hundred pounds of sand of known weight and sieve analysis were shoveled into the inlet channel and allowed to deposit in the chamber. When all the sand was settled, the flow was diverted and the chamber drained. The chamber was divided along its length into 10 ft. sections, and the sand which had deposited in each section was weighed and analyzed as to size distribution. From the results of these measurements, the removal of grit in the proposed Detroit chambers was estimated.

In a discussion of Hubbell's paper, Camp (24) showed that the actual removal of sand in the Dearborn and Grand Rapids chambers was 90 per cent and 93 per cent, respectively, of the removal predicted by means of the simple theory of sedimentation of discrete particles. The agreement is considered to be very good in view of the fact that the simple theory does not account for the effects of short circuiting and transportation in suspension by turbulence. A method for correcting the theoretical removal for the effects of short circuiting was described. Further studies have been made by Rouse (135) upon the effect of turbulence on the sedimentation of discrete particles. Papers which throw some light upon transportation of discrete particles in suspension and along the channel bottom were presented by Chang (28) and by Howard (83).

Hubbell's (85) model studies of circular primary settling tanks for the Detroit sewage works give much needed information regarding the hydraulic characteristics of radial flow tanks. The model was constructed at a scale ratio of 1:24 to represent a tank having a 200 ft. diameter and an average depth of about 14 ft. The manufacturer's design for the standard or conventional type inlet consisted of a 7 ft. tunnel feeding into a 90° elbow of 5 ft. radius with a vertical, slightly diverging riser, on which was set a standard type diffuser consisting of vertical ports between columns supporting a baffle disc at the top. The

diffuser was surrounded by a solid baffle ring 32 ft. in diameter and extending from above the water surface to within 6 ft. of the bottom of the tank. Dye studies with this type of inlet indicated a strong tendency for the sewage to short-circuit towards the side of the tank away from the inlet tunnel. Strong currents were noted in a direction downward from the ring baffle and outward along the bottom, with return rollers above directed toward the inlet and affecting the central area comprising half the total area. At the maximum discharge rate, the first dye passed in 12.7 per cent of the nominal detention period and velocities near the floor just outside the baffle were about 20 to 30 times the nominal average velocity. The flowing-through period was about 85 per cent of the theoretical time but was variable due to the unstable character of the flow.

A new inlet was developed experimentally by Hubbell after trying many different schemes. For Detroit conditions, the 90° elbow was found to be unsuitable; and it was recommended that the tunnel should end in an abrupt enlargement into a circular well provided with vertical guide vanes extending up into the riser. The conventional diffuser was replaced in the model with a multiple-plate diffuser consisting of flat plates set one above the other with concentric holes of decreasing diameter. Each plate was designed to pick off its proportional part of the rising flow and divert it horizontally into the tank. Finally the solid ring baffle was replaced by a fixed spiral flow baffle consisting of 48 blades 18 in. wide and submerged 7 ft. The function of these blades is to direct the sewage into the tank tangentially from the central inlet and thus impart a spiral motion to the liquid.

Dye and float tests on the model equipped with the developed inlet showed considerable improvement with regard to flowing-through time. The rollers were eliminated, first dye passed in 27 per cent of the detention period and the flowing through ratio was about 91 per cent. The maximum radial velocity was only about one-third of that observed with the standard type inlet. Since the direction of flow near the center was spiral instead of radial with the new inlet, the actual maximum velocities were, however, about the same as with the standard inlet.

Model studies were also made on rectangular primary tanks for Detroit (25). The alternate rectangular tanks, which were subsequently adopted for the city, had the same capacity as the circular tanks but each was divided into seven longitudinal compartments 16 ft. wide by 272 ft. long. In the tests on the model tank at the average 1950 flow, the first dye appeared in 55 per cent and the center of mass in 94.5 per cent of the theoretical detention period. There were no back rollers in the tank.

Chemical Treatment

The installation of more flexible chemical handling equipment for new chemical treatment plants has come with the proper appreciation that the method of chemical treatment is best decided upon after a plant

is put into operation. The type of treatment depends upon the character of the sewage, the cost of chemicals and the handling of chemicals. The two latter functions depend upon the location and size of the plant. When used the year around, the type of treatment may vary throughout the year due to differences in response to certain chemicals in summer and winter or seasonal influx of certain trade wastes which are handled better by other than the normal method of treatment. An example of this type of installation is the plant at Danville, Illinois, described by Nemoyer (123). Alum, lime, ferric sulfate and liquid, crystalline and anhydrous ferric chloride can be applied to the sewage with the equipment available.

The importance of an intelligent survey of results obtained with various chemicals at a given plant is being more thoroughly appreciated. Stimulation in obtaining such information has been afforded by the various chemical manufacturers. However, it is best for the operator to work in conjunction with the chemical manufacturers, and not to lean on them. It is for him to decide which chemicals will be used. To judge this fairly he must know what results were obtained, how much chemical was used and what problems arose in feeding and applying the chemicals. He must supplement the data obtained by the manufacturer with additional data of his own to determine whether, under conditions of normal operation, he can obtain similar results.

Haseltine (64) at Butler, Pa., Bell at Essex Fells, N. J. (13), and Hood at Ridgewood (82) have shown the value of such work in the past year, not only for determining the treatment best suited to the sewage handled at the lowest cost, but for handling problems peculiar to the particular job. Haseltine built up a fine case justifying the installation of much needed additional equipment. Bell not only halved previous chemical costs but solved the problem of digester overflow, which was upsetting clarification. By prechlorinating the overflow liquor, periods of poor flocculation were eliminated. Hood learned how to handle Monday's influx of laundry waste. Controlled application of sulfuric acid after the usual alum treatment solved this problem.

That chemical treatment is practical for the small plant was definitely proven. Show and Ditmars (149), in an investigation of the Essex Fells plant, designed to treat only 200,000 gal. per day, showed that chemical cost could be kept below $8.00 per million gallons. At Ridgewood, where about one million gallons per day are treated, the cost ran to less than $6.00 per million gallons. Both of these plants employed alum which seems to be increasing in popularity, particularly at small installations. In the two plants mentioned above, alum gave much lower costs than did ferric salts. However, this is not always the case. Haseltine obtained best results with a ferric salt and lime, but cases have been observed where alum floc would not settle, or where the cost was far above that of ferric chloride alone. Attention should be called to the use of sufficient lime to reduce substantially the ferric salt dosage necessary for clarification. Small amounts of lime are often ineffective while an increased dosage will usually permit the use of

very little coagulant. The pH should be raised to at least 9.0. When this is done the costs of chemicals will generally approach more closely that of alum, and effluents colored by iron will not be obtained.

Considerable attention has been given in the southwest to the generation of ferric chloride by treating iron with chlorine. Whedbee and Zeller (179) reported experiments at Dallas and Yaffe (186) at El Paso, Texas. Carollo (27) described a new plant embodying this feature at Phoenix, Arizona. The Dallas experiments, employing separate reaction and oxidizing towers, were shown to be only about 50 per cent efficient, as a considerable portion of the chlorine was converted to hydrochloric acid rather than ferric chloride. The authors arrived at the conclusion that this method of obtaining ferric chloride was too expensive when this low conversion was obtained. They also stated that difficulties encountered in operating the generator were numerous.

The El Paso experiments led Yaffe to the conclusion that when two towers were used, both containing iron, a conversion of almost 100 per cent could be obtained if a means of preventing "hydrogen binding" was employed. He stated that steel turnings were better than cast-iron turnings as they contained less impurities and were larger, thus giving less packing troubles in the towers. He believed that the manufacture of the coagulant should be kept separate and distinct from the treatment process. An attempt should not be made to generate the ferric chloride as needed in the treatment process, as attempts to change the production rate in the generator not only lower the efficiency but require too much attention on the part of the operator. From these experiments it appears that a good deal of knowledge is lacking and much work must be done before this process becomes reliable. The installation of special equipment to produce a concentrated chlorinated copperas solution for sludge conditioning at Baltimore, Md., was described by Genter (50). Low priced copperas is available locally, and investigation indicated that this coagulant can be most economically utilized to condition digested sludge.

Much attention has been directed to the "Biochemical Process" advanced by the Guggenheim Brothers, Inc. An excellent summary of engineers' reports, pilot and plant scale data and general information was published (56). It was established that an oxidation of carbonaceous material took place on aeration of the chemical sludge-sewage mixture unaccompanied by nitrification. Some of the soluble B.O.D. was removed, thus this process was partially chemical and partially biological. The effluent produced was of better character than one obtained by plain chemical treatment, because of the oxidation of part of the solubles. Results obtained fall between those produced by chemical treatment and the activated sludge processes. The use of an iron salt may aid coagulation, accelerate the oxidation process, and give the sludge added stability. The two latter factors may be due to the iron acting as an oxygen carrier, in accordance with Warburg's theory.

Rudolfs and Gehm (139) studied the effect of the order of addition of chemicals on sewage clarification. Lime and sulfuric acid were used

as coagulation aids and ferric chloride and alum as coagulants. When lime and ferric chloride were used, the addition of lime first gave somewhat better results than did the reverse order. With ferric chloride and acid the addition of the iron salt prior to the acid gave by far the best results. The results obtained with alum followed quite closely those obtained with ferric chloride. Lime and acid were found to function more as coagulating than mere pH adjusting chemicals and should be considered as coagulation aids.

Gehm (48) reported a series of experiments dealing with the effect of the non-settleable sewage solids on the amount of coagulant necessary for coagulation. From the results obtained it appears that this fraction of sewage does not determine the coagulant demand.

The use of chemicals prior to the activated sludge process in England led Nixon (126) to warn against allowing the pH value to get below 6.0 in the sewage flowing to the aeration tanks. If acid or acid salts are used or trade wastes are acid, the addition of a neutralizing chemical is necessary. Donaldson (36) presented an interesting and useful table containing a complete list of all modern chemical treatment plants in this country including capacities, type of treatment and period of treatment. He observed that, with only two exceptions, supplementary devices were employed when chemical treatment was used the year around. Streander (163) also called attention to the widespread use of supplemental chemical treatment.

From the standpoint of practical application, the value of chemical treatment in reducing capital cost by its ability to handle daily and seasonal peaks in sewage quantity or sewage strength has not as yet been adequately explored.

For this purpose careful studies of cost, made in existing plants under closely controlled and intentionally varied conditions should yield information of considerable value. Such studies need not be limited to plants specifically designed for chemical treatment; plants operating at capacity, or overloaded, should give especially worthwhile information. Schroepfer's (147) work is invaluable as a general comparative study of the whole field of sewage treatment, but supplementary cost studies in greater detail of the various processes, and in particular of chemical treatment as an adjunct to different processes, are greatly desired. Schroepfer's study indicates the economic advantage of chemical treatment under seasonal conditions. If careful studies of its effect on daily fluctuation in load are made, perhaps further economies may be indicated.

Filtration and Straining Devices

The past year has been the start of operation of a number of magnetite filters of the downflow type and the use of finer magnetite. Consequently more data on operation, especially at the larger plants, have become available even though not all of the important information has appeared in print. Experimental magnetite filters at the West Side

Sewage Treatment Works of the Sanitary District of Chicago were operated in parallel for straining chemically and non-chemically precipitated Imhoff effluent (76).

Operation was started of upflow magnetite filters for straining activated sludge effluent at Greece, N. Y., a rectangular downflow magnetite filter for straining plain settled and chemically precipitated effluent at Barberton, Ohio, and rectangular units for straining trickling filter effluents at the Southerly Plant, Cleveland, Ohio (104).

Black (16) reported several months' operation of settled effluent, without chemicals, filtered through six magnetite filter units at Denver. The influent to the filter had 45 p.p.m. suspended solids and effluent from the filter 28 p.p.m. The overall removal obtained by settling and filtering was 84 per cent for suspended solids and 59 per cent for B.O.D. The Platte River below the plant showed 6 p.p.m. B.O.D. in May and 22 p.p.m. in June, which even without chemical treatment was less than the 40 p.p.m. standard set by the Board of Health.

Holmes (81) stated that a magnetite filter was being installed to take either primary settled or final activated sludge settled effluent at the Ley Creek, Onondago County, N. Y., plant. This magnetite filter is of a circular downflow type with fine magnetite and includes interior concentric cascades for introducing dissolved oxygen. It is the first downflow circular filter in a separate structure.

Schroepfer (147) presented an interesting study on the economics of magnetite filters based on data from nine plants. He stated that reductions accomplished were a function of strength of filter influent, and that there was considerable variation in the filter rates at these plants varying from 1.8 to 3.0 gal. per sq. ft. per minute. Factors affecting design are filter effluent, sand size and daily variation of flow. Based on conditions at Minneapolis, the cost of filtration was equal to chemical treatment if 15 to 20 p.p.m. suspended solids were removed by filtering, and to plain sedimentation if 24 p.p.m. were removed. On a B.O.D. basis, filtration was more economical than chemical treatment, if 12 to 15 p.p.m. were removed and as economical as sedimentation if 16 to 17 p.p.m. were removed.

A 1 in. to 3 in. coal mat on a Riensch-Wurl (3) screen was found to clog due to fine solids from the industries at Niagara Falls. Experiments with a ¼ in. mat took out insufficient solids and a ¼ in. to ⅜ in. mat of fine coke was found to be operative if the entire mat was removed at each location.

Tests conducted at Goshen, Indiana, by Hurwitz and Miller (87) showed 62 per cent overall removal of suspended solids, and 47 per cent removal of B.O.D. by settling followed by a coarse upflow filter. The magnetite filter removed 23 per cent of the suspended solids and B.O.D. reaching it, thereby improving the overall treatment by 12 per cent in suspended solids and 14 per cent in B.O.D. as indicated by simples below and above the filter.

Several sand straining devices, built in clarifiers, have been installed in the Raritan Valley, N. J., but no results have been published.

Zack (187) and (188) described and discussed the types, the present installations and the uses of filter effluent strainers.

Chlorination

Considering the extensive adoption of chlorination, either as an integral process of sewage treatment or as an accessory to other types of treatment, the reports on fundamental research in the application of chlorine are very limited. It is of interest, in plant operation, that manufacturers of liquid chlorine have developed a process, as described by Hedgepeth (71), to eliminate impurities which might cause feeding difficulties. These liquid chlorine impurities were shown by Hedgepeth and Riggs (72), who used a more accurate analytical method, to consist largely of ferric chloride, hexachlorethane and chloroform. The development of a new type of automatic chlorinator, designed to vary the dose geometrically in order to compensate for simultaneous increases in flow and in strength of sewage, was noted by Beyer (15).

Papers by Henkle (74) and by Singleton (152) recognized the desirability of providing adequate facilities for the safe handling of chlorine. Woodward (184) described the use of chlorinated water sprays, at Laguna Beach, Cal., to deodorize the foul air exhausted from a completely enclosed activated sludge plant situated within the city.

Chlorine for Disinfection.—Results of laboratory and field studies conducted by Symons, Terhoeven, and Torrey (164) on domestic and industrial sewage at Buffalo, N. Y., have been made available. While the Bird Island Laboratory modification of the Standard Method of chlorine demand determination, which was employed in these studies, indicates a demand in general 10 per cent lower than the Standard Method, the chlorine doses based on these demands have been found to produce bacterial kills of 98 to 99 per cent under local conditions. Chlorine demand per capita was reported as 0.00467 to 0.0050 pounds per day and, in predicting chlorine consumption, per capita demand was indicated as a more important figure than parts per million demand. Temperature of the sewage, between 12 and 24 degrees C., appeared to have little effect on the chlorine demand. Below this range the demand (depending on type of sewage) was 65 to 74 per cent of that at higher temperatures. For relatively fresh domestic sewage the average chlorine demand was 4 to 5 p.p.m. and for strong sewage 8 to 11 p.p.m. Industrial waste and sewage mixtures, under Buffalo conditions, averaged 30 p.p.m. chlorine demand and variations of from 30 to 560 per cent for a given day were found.

In a sequel to this paper, Symons, Simpson, and Torrey (165) summarized over 600 examinations made to determine the bacterial kill accomplished by chlorination. Under the experimental conditions at Buffalo, the study indicated sedimentation of strong sewage, while reducing suspended solids by 40 per cent, affected only a negligible reduction in chlorine demand. During sedimentation the number of gas formers was practically doubled. To completely satisfy the chlorine demand,

a contact period of 15 minutes proved to be sufficient and, with a chlorine residual of 0.1 p.p.m. present at the end of that time, effected approximately a 99 per cent bacterial kill in either settled or unsettled sewage. When sewage was diluted with untreated lake water (1:320) relatively no re-growth of sewage bacteria took place.

Wittwer (183) described chlorination experiments with varying chlorine dosages during summer disinfection at the Rahway Valley, N. J., Joint Meeting Sewage Treatment Works. Chlorine demand tests were run daily to correlate periodic changes in sewage strength with the quantity of chlorine required to produce the necessary residual. A probable dosage of 10 p.p.m. will be necessary to maintain the necessary residual. Pre- and post-chlorination were used by Marshall (114) at Geneva, N. Y., for odor control and disinfection during the summer months, while only post-chlorination was required during the winter. Contact periods provided are: 4 hours for pre-chlorination and 40 minutes for post-chlorination. Residual chlorine tests and chlorine dose adjustments are made six times daily to maintain a residual of 0.5 p.p.m.

Rudolfs (138) reviewed progress in New Jersey on the correction of pollution. Modern treatment plants have been constructed or old plants have been remodelled on three separate drainage areas. A summary of the treatment processes shows that 18 plants will employ chlorination, probably largely on a seasonal basis.

Bardsley (7), while making a comparative study of coliform organisms in chlorinated and non-chlorinated swimming pool waters, found that the chlorinated water samples had a preponderance of *aerogenes*, while the non-chlorinated had about equal numbers of *aerogenes* and the intermediate types. With increased chlorination the numbers decreased but after the disappearance of chlorine vigorous regrowth occurred.

Odors and Hydrogen Sulfide.—At Butler, Pa., Haseltine (62) secured effective control of odors by applying doses of chlorine insufficient to produce a residual. Partial pre-chlorination was essential to the success of chemical coagulation, though it was not necessary to add a dose sufficient to produce a residual in the coagulation stage. Nearly all sewer lines were found by Hood (82) at Ridgewood, N. J., to be heavily furred with gray algae. The predominance of *beggiatoa* was believed to be responsible for the reduction of sulfates to hydrogen sulfide and for consequent difficulties in chemical coagulation. Application of chlorine, in doses stated as "heavy" but actual amount used not given, for one week did not dislodge fungus from the sewers. Copper sulfate and flushing did prove effective in loosening growths. A marked reduction in chlorine demand of the sewage received at the plant followed this treatment and the process was repeated, with further chlorine demand reductions.

Chlorine in Chemical Coagulation Processes.—Bell (12) reviewed chemical coagulation practice at Essex Fells, N. J., and noted that flocculation was adversely affected by return of digester supernatant. Heavy pre-chlorination of the raw sewage, during the period of super-

natant liquor return, was found to be a practical corrective measure. It is also significant, as pointed out by Shaw and Ditmars (149), that pre-chlorination proved effective during the use of chlorinated copperas as the coagulant at this plant. Even though the chlorine demand was only partially satisfied, B.O.D. of the effluent was reduced to 27 p.p.m. as compared with 42 p.p.m. B.O.D. when no chlorine was used. Overall plant removals were improved when a pre-chlorination dose of 7 p.p.m. was applied, even though the doses of copperas and lime were simultaneously reduced by 20 per cent.

Chlorine and Trickling Filter Operation.—The ponding of trickling filters at Slough (West of London) was reported by Kershaw (103). A rapid growth of thick reddish slime, stringy rather than gelatinous in nature, almost completely sealed the filters. Lengthy studies on pre-treatment with chemicals indicated the application of "Chloros" to the filter dosing tank to be most effective. Liquid chlorine equipment was installed, and chlorine was applied at an average dose of 10 p.p.m. Development of the slime growth was checked by this treatment and progressive cleaning of the top 6 inches of filter media had been accomplished at the time of the report.

Studies on the chlorination of milk wastes, as summarized by Agar (1), show this treatment to be effective in delaying decomposition. Where such wastes discharge into a small stream, which shortly enters another stream providing adequate dilution, chlorination of the wastes might delay decomposition for the required period of time. Loreaux (112) noted that practicable methods of beet sugar waste treatment are available but that these do not relieve taste and odor problems caused by the waste entering surface water supplies. The biological stabilization of such wastes by long storage and oxidation of the effluent with chlorine during discharge was proposed.

Chlorine for Grease Removal.—The efficiency of this process has been confirmed by Keefer and Cromwell (101) in semi-plant scale tests at Baltimore, Md. Studies on domestic sewage showed increases in scum, produced by applying small doses of chlorine gas in the pre-aeration process, to range from 149 to 847 per cent of the scum obtained by pre-aeration without chlorine. Variations in the amount of air and chlorine applied, and in the detention time provided, indicated even minimum doses of air (0.064 cu. ft. per gal.) and of chlorine (1.0 p.p.m.) during 5 minutes detention capable of doubling the yield of scum.

Full-scale use of this process has been studied at the Lancaster, Pa., activated sludge plant. Wiest claims (180) aero-chlorination, using solution chlorine applied in the pre-aeration channel, to be highly effective. Comparative runs showed the use of an average chlorine dose of 2.0 p.p.m. chlorine increased the amount of scum from 3.5 pounds, obtained with pre-aeration alone, to 12.5 pounds per million gallons. The total grease content removed by this aero-chlorination treatment, followed by sedimentation, was found to be 80 per cent. Grease in the return sludge has been reduced from 21.63 per cent to 5.61 per cent.

Improved plant operation, with absence of bulking troubles, is credited to this method of treatment.

It was noted by Killam (104) that aero-chlorination has been provided for on a large scale at the remodelled Westerly plant in Cleveland, Ohio. Dry chlorine gas will be introduced into the air header near the down-drop pipes which are rubber lined to preclude the possibility of corrosion below the water line.

Activated Sludge

Mechanism of the Activated Sludge Process.—Ruchhoft, McNamee and Butterfield (137) have determined that the rates of oxidation in the activated sludge process vary considerably according to the conditions of operation and are much greater than the biochemical oxygen demand rate for streams. This high rate is made possible by continuous feeding and the maintenance of proper aerobic conditions which promote the development of enormous numbers of bacteria. The oxidation capacity of the sludge is limited by its biochemical character and activity and the resulting oxidation is not proportional to the B.O.D. of the organic substances added as food. They emphasize the practical value of tests to determine the oxidizing activity of the sludge.

It has been generally accepted that biological reactions cannot be speeded up by increasing the concentration of dissolved oxygen and it has been stated that theoretically an activated sludge plant may be run with the lowest oxygen concentration which can be consistently maintained. Pomeroy (132) has determined experimentally that, with large concentrations of oxygen (20 to 40 p.p.m.), the rate of oxidation may actually be decreased. Hicks (80) built an experimental plant consisting of five tanks placed one above the other in a closed system so that air released at the bottom of the lowest tank passed, in turn, through all five units. The top tank was four feet deep and the others five feet. He reported that, with only 25 per cent of the aeration period and 12.5 per cent of the air, this experimental unit produced results comparable to those obtained in a large plant treating the same kind of sewage in the conventional manner. It was brought out in discussion of the paper that the increased pressure necessary to force air through the system would increase the average saturation concentration by only 10 per cent and that perhaps the greater surface exposed and the high rate of air addition per unit area of liquid surface may be important factors. Increased biological activity because of increased concentration of oxygen beyond that necessary for carrying on the process is difficult to reconcile with our present theories.

Members of the staff of the New Jersey Agricultural Experiment Station have continued the study of the clarification stage of the activated sludge process. Heukelekian and Schulhoff (79) have isolated from activated sludge and sewage several pure cultures of organisms which have the ability to clarify sewage and, upon longer periods of incubation, to destroy sludge. Experiments carried on by Ingols (90)

(91) indicate that the removal of ammonia is not a base-exchange reaction. The failure to remove ammonia in the absence of biological activity indicates that the uptake of ammonia by activated sludge depends upon biological phenomena. In a similar manner soluble organic compounds such as glucose and amino acids were also removed by biological processes. Heukelekian and Ingols (77) (78) have demonstrated that activated sludge-sewage mixtures can hydrolyze some organic materials not utilized directly. For example, starch is rapidly hydrolyzed and the products of hydrolysis are oxidized at about the same rate they are produced. The rate of hydrolysis depends on the quantity of starch, the concentration and quality of the sludge, the air and the presence of sewage as food. The rate of hydrolysis of nitrogenous substances depends on the complexity of the molecule or the stage of hydrolysis. Some compounds yield amino acids, ammonia and nitrate nitrogen with one to two hours of aeration. This hydrolytic action and clarification take place simultaneously.

The exact role of oxygen in biological treatment processes and the nature of the end products have not yet been clearly defined. In order to trace the fate of carbon during activated sludge oxidation, Wilson and McLachlan (181) established a carbon balance on a laboratory scale activated sludge plant. They found that instead of carbon dioxide being a major product of aerobic oxidation, only about 10 per cent of the transformation products of carbon appear as carbon dioxide in the effluent gases. The concentration of carbon dioxide in the effluent liquor was approximately equal to that in the original sewage. They suggest that much of the carbon must be assimilated in building the body substance of plant and animal organisms in the sludge and that the transference of carbon from the sewage to the sludge in this way is the major factor in purification.

Although a chemical theory of the activated sludge process is not new and has generally been discarded in favor of a physical-biological one, Shibata (150) believes the principal factor in the purification of sewage colloids and suspended solids to be the physical-chemical and electro-chemical action of inorganic hydroxides. The living organisms which ferment the coagulated organic matter play a secondary part. Satisfactory purification was obtained by aeration in the presence of ferric and aluminum hydroxides without activated sludge. The concentration of inorganic hydroxides (20 per cent) used in the test was much greater than that present in the activated sludge used as a control (20 per cent of sewage flow). The conclusions would have been more convincing had the author used a concentration of hydroxide more nearly equal to that in normal sludge. For best results, Shibata reports that the pH should be between 5.8 and 7.5 and sufficient oxygen should be added by aeration to avoid the change of hydroxides to sulfides, with a subsequent lessening of coagulating power.

Operation.—A number of studies have been carried on during the past year which were intended to increase the efficiency of the process.

At Chicago, Herrick (76) reported that sewage was aerated in a tank containing sponge rubber blocks. Even with cubes as small as one-half inch the spaces in the sponge rubber became filled with solids and the blocks were too heavy to circulate with spiral flow. Herrick also stated that very weak settled sewage (B.O.D. 66 p.p.m.) was treated by the activated sludge process with aeration periods of only 1.6 hours and air consumption of only 0.32 cubic feet per gallon of sewage. During a period of more than three months the reduction in B.O.D. was 77 per cent.

A new development in activated sludge treatment has been reported from Barking (9), England. The London County Council has completed construction of double deck aeration tanks. By means of paddles, sewage inoculated with reaerated activated sludge is circulated through channels which provide a total flow length in six tanks of 6,400 feet. The plant has a capacity of 66 m.g.d. (Imperial) and is designed to produce a stable but not highly nitrified effluent.

Ippolito (92) has used the clarifying power of excess activated sludge to partially purify supernatant liquor from sludge digestion tanks. First attempts to aerate a mixture of supernatant liquor and activated sludge did not produce satisfactory effluents. The supernatant liquor seemed to act as a poison and paralyzed or destroyed the microscopic life of the activated sludge. Believing that the poisonous effect was caused by dissolved gases, he pre-aerated the digested sludge liquor for 30 minutes, then added an equal volume of activated sludge and aerated the mixture four hours. In this way, the B.O.D. of the liquor was reduced from 825 to 1,000 p.p.m. to only 200 to 275 p.p.m., which was less than the B.O.D. of the raw sewage.

Roe (134) and Kappe (98) have concluded that, considering the cost of construction, interest, depreciation and power costs, mechanical aeration is less expensive than diffused air for small plants, perhaps those treating less than 1 to 1.5 m.g.d. They agreed that air diffusion is cheaper for flows above 1.5 m.g.d. Flexibility and adaptability of equipment to permit maximum efficiency in power usage are important.

Sludge Bulking.—Haseltine (66) has re-studied the action of lime in the control or prevention of bulking and concluded that it is most effective when applied near the aeration tank inlets. The benefits to be derived are due to lime plus aeration and not to lime alone. He concluded that, in bulking, biological oxidation lags behind adsorption. When the rate of biological oxidation is limited by the rate of elimination of carbon dioxide, which is toxic to bacterial activity, lime is effective in controlling or eliminating bulking. The lime may be added intermittently to prevent the occurrence of bulking or continuously for the elimination of bulking already present.

Hudson (86) found that 5 p.p.m. of chlorine added to the raw sewage eliminated severe bulking resulting from the treatment of a strong septic sewage containing milk wastes. He believes that the recovery of the plant would have been more rapid if chlorine had also been applied to the return sludge.

Molitor (122) reported that periods of "unrest," accompanied by sludge bulking, occur for two to four weeks every spring and fall at the activated sludge plant of Morristown, N. J. The floc becomes fine and fluffy and a slimy scum indicates filamentous growths. Continuous mild chlorination of return sludge was found to remedy the condition. A further report on return sludge chlorination in an overloaded plant at Houston, Texas, was presented by Steel and Ehlers (159). Application of an average chlorine dose of 5.34 p.p.m. resulted in improvement in plant operation, reduction in numbers of *sphaerotilus*, and alleviation of bulking difficulties.

Shibata (150) continued his chemical theory of the activated sludge process to include the bulking of sludge. He attributed bulking at the Mikawashima plant in Japan to fractional settling in the Dortmund tanks. He reported that heavier solids containing a high proportion of inorganic matter settle to the bottom first and are removed as excess sludge. The lighter solids are returned to the aeration tanks making the sludge in the aeration tanks progressively higher in organic matter and lighter in weight. Bulking was eliminated by the addition of sufficient aluminum hydroxide to increase the ash content of the sludge to normal.

It has become increasingly clear that in reporting the efficiency of activated sludge plants, the work done by the plant must be taken into consideration. The common method of reporting operation data in kilowatt hours per million gallons of sewage completely disregards the strength of the sewage and gives equal credit for the treatment of weak and strong sewages. Roe (134) recommends "the kilowatt hours per pound of B.O.D. removed by aeration" as a suitable yardstick to measure aeration power, the principle item of operation cost of activated sludge plants. This unit was suggested and adopted by engineers of the Illinois Department of Health. It is easy to calculate and gives proper credit for the work done by the plant.

Trickling Filters

(*Editor's Note.*—The section on "Trickling Filters" was not received in time to be included in the review.)

Sludge Digestion

The progress of fundamental research in sludge digestion has been notably slow. The exhaustive studies on the fundamental character of sludge digestion and factors influencing the rate of digestion were followed with a period of consolidation in which the knowledge gained has been put on a practical basis and exploited. To avoid a stalemate in the art of sludge digestion two avenues remain open: (*a*) further studies of fundamental nature and of the organisms responsible for liquefaction and gasification, with a view of further accelerating each phase separately or simultaneously, (*b*) further extension of the art of sludge di-

gestion to the field of disposal of industrial wastes either separately or in combination with sewage.

The trend in the type of sludge digestion tanks has been accentuated along the lines noted before, namely, a greater number of plants where stage digestion and mechanization are employed, with gas utilization for heating and power production. The design features and operating results of a great number of newly constructed plants are still unavailable.

Research.—Two apparently conflicting reports were made on the effect of activated carbon on sludge digestion on the basis of some laboratory experiments. Flower, Budd and Hauck (44) found that the addition of 200, 400 and 800 p.p.m of activated carbon to a mixture of fresh and activated sludge increased both the rate and volume of gas, the more pronounced effect being obtained with a 200 p.p.m. dosage.

The pH value was increased as a result of carbon addition. The amount of solids in the supernatant liquor increased with the higher dosages of carbon. Odor reduction was decided, with a reduction of 70 per cent with 200 p.p.m. application.

Keefer and Kratz (100) on the other hand found that digestion of unseeded fresh solids was retarded by the addition of 8 per cent of carbon by weight on the basis of volatile solids. With seeded solids the results obtained from a number of tests were at variance with the results published by them previously in that, in four of the six tests, the untreated sludge digested more rapidly than the material treated with activated carbon.

It is difficult to compare the results of these two investigations because of the differences (*a*) in the type of solids digested, (*b*) in the method of expressing the dosage of carbon and (*c*) the lack of sufficient data to convert the dosages to comparable basis.

Rudolfs and Ingols (142) reported that the aging of fresh solids increased the amount of skatole from 1.2 to 160.0 p.p.m. after 4 weeks of incubation, without ripe sludge. The quantity of indole was not increased to the same extent as that of skatole. Ripe sludges contained on an average 0.7 p.p.m. indole, with only faint traces of skatole. In order to obtain the maximum growth promoting value from the sludge when applied to the soil it should therefore be used in a partially digested state.

Barker (8) reported a methane fermentation of ethyl alcohol in which large quantities of butyric and caproic acids were formed in addition to acetic acid. This fermentation was brought about by *Methano-bacterium Omelianskii* and an associated spore-forming bacterium. At the same time that these acids were produced from ethyl alcohol there occurred a reduction of carbon dioxide to methane.

The research work in connection with the digestion of garbage has somewhat subsided. It is of interest, however, to note the report of some investigations by Welch at Flint, Michigan (177), where digestion of a mixture of sewage solids and garbage took place readily, producing 11.5 cu. ft. of gas per cu. ft. of volatile matter. Mixtures of either

sewage solids or of garbage in combination with the lime sludge from water-softening plant also digested readily.

Stage Digestion.—Haseltine (63) reported on the extensions to the Topeka, Kansas, plant providing 3-stage digestion with a total design capacity of 3.0 cu. ft. per capita. The waste activated sludge was thickened in a picket fence type thickener from 0.4 to 0.6 per cent to 3 to 4 per cent. The raw solids and the thickened activated sludge were digested in the primary tank, provided with a turbomixer for a period of 20 days. The sludge was then transferred to the secondary tank, which was provided with a gentle stirring device, and finally transferred to the tertiary tank, which was provided with a gas holder but no stirring, where further thickening and digestion takes place.

Ardern, Jepson and Klein (5) described a method of digesting primary and densified activated sludge for a period of 10 days at 25 to 30° C. in a covered tank with floating gas holder, followed by three weeks of digestion in open secondary tanks without heating. The raw and activated solids were pre-heated in a tubular pre-heater and mixed with an equal volume of seed. The sludge withdrawn from the bottom of the primary digestion tank was 60 to 70 per cent digested and that from the secondary tank 75 to 80 per cent digested, with the production of 3.5 cu. ft. of gas per lb. of dry organic matter containing 71 per cent methane. Zoning occurred in the primary tank.

Sperry (157) reported the change from single- to two-stage digestion at Aurora, Ill., in order to meet the overloading of the tanks. Records of four months' operation in the latter part of the year are compared with the previous eight months. The gas yield during the entire year increased by 8.3 per cent but this was attributed to the addition of secondary sludge not used up to the present. The gas yield per month or per day was greater during the period when the tanks were operated as a two-stage system; and on the basis of equal amounts of volatile matter added the increase was 9 per cent. The composition of gas was not materially changed but had a slightly higher B.T.U. value. A gas with considerably higher methane content was obtained from the first stage but the average for the two stages combined was only slightly higher in methane and B.T.U. than the gas produced by the single-stage process. The hydrogen content of the gas from single-stage operation was 2.8 per cent and from two stage 2.2 per cent.

Waterman and Rostenbach (176) describe the two-stage digestion at Iowa City, Ia. The observation is made that aluminum pipes for hot water circulation failed after 20 months and were replaced by wrought iron pipes. The failure was due to corrosion on the outside of the pipe. It is reported that hydrogen content of the gas was as high as 10.0 per cent although no industrial wastes were present in the sewage except wastes from milk plants and laundries.

Wittwer (183) reported a 63.3 per cent reduction of volatile solids in the Rahway Valley, N. J., Joint Meeting two-stage digestion tanks, with 1.27 cu. ft. of gas per capita per day, during the first seven months operation of the plant.

The design and operation of the Coheshill sewage disposal plant of the Birmingham, Tame and Rea districts drainage Board was reported by Vokes (172). The total digestion capacity of 3.24 cu. ft. per capita was distributed in five primary and three secondary tanks. Gas collectors were on the primary tanks and the gas yield was 0.78 cu. ft. per capita.

A general summary of the salient features of some of the single and two stage digestion tanks are given in Table I.

Operation Experiences.—Andersen (2) emptied the digestion tanks at Rockville Center, N. Y., for general inspection after seven years of operation. The piping and the concrete inside the tank was in good condition. There was about 3/16 in. of scale on the heating coils in some places. After drying the scale came off readily. Hicks (80) found that pre-heating of sludge by radiators with rough surfaces was not successful due to the viscous nature of the sludge and the gas film around the radiator acting as an insulator. Installation of smooth iron pipes in the pre-heating tank solved the difficulty. The sludge could be heated to 100° F. in 12 hours. Because of the high rate of gas evolution no scum has been formed in the digester and therefore no circulating mechanism has been necessary. Also no supernatant could be found and the sludge had a uniform vertical distribution.

Smith (153) reported performance of the unheated digesters at the village of Canton in the northerly part of New York State. Digestion capacity of 2 cu. ft. per capita was available, with only an earth embankment and with a temperature in the digesters of 42 to 45° F. during about five months of the year. It is difficult, however, in the absence of analytical results to determine whether the sludge was well digested. During the second year, when the conditions were better, the sludge dried on an average within 10 days in glass covered beds.

An estimated 64 to 66 per cent reduction of solids in the digesters at Morristown, N. J., was reported by Moerk and Eisenberg (121). But considering that the sludge was retained 7.8 years the findings are not surprising since 60 to 65 per cent reduction of volatile matter can be obtained regularly within the more usual detention periods employed at present.

Imhoff Tanks.—The operation of Imhoff tanks at Tonawanda, N. Y., is described by Samson (143). The two circular Imhoff tanks, built in 1924, with inlet and outlet on opposite sides, were supplemented with two more similar tanks in 1927 giving a total capacity of 2 cu. ft. However, the more recent tanks were provided with only 10 per cent gas vent area in relation to the surface area of the tanks, instead of 20 per cent as in the original tanks. The tanks with the smaller area of gas vents have given more difficulty. Foaming has been a great problem, especially in the spring. Pre-chlorination in conjunction with more regular sludge withdrawal was effective in controlling foaming. However, at the time pre-chlorination was started, a regular schedule for withdrawing sludge was adhered to and it is difficult to apportion a definite value in control of foaming to each of these factors.

TABLE I

Reference	Location	Type of Solids	Type of Tank	Temp. F°	Capacity, Cu. Ft./ Capita	Gas Production		Volatile Matter, Reduction Per Cent
						Per Capita	Per Lb. Vol. Solids	
Haseltine (63)	Topeka, Kan.	Primary and Activated	3 Stage	85–94°	3.0–3.8°			
Arden, Jepson and Klein (5)	Manchester, Eng.	Primary and Activated	2 Stage	78–86°	41 days		3.5	
Vokes (172)	Birmingham, Eng.	Primary and Activated	2 Stage	69°	3.25	0.78		
Sperry (157)	Aurora, Ill.	Primary and Secondary	2 Stage	81–89°	—		10.8	
Waterman, Rostenbach (176)	Iowa City, Ia.	Primary	2 Stage	83°				
Wittwer (183)	Rahway, N. J.	Primary	2 Stage	80°		1.27		63.3
Singleton (152)	Atlanta, Ga.	Primary	2 Stage	Heated		1.65		
Brockway (21)	Witchita, Kan.	Primary	Fixed Covers	85–95°		2–3	15	
Black (16)	Denver, Col.	Primary	2 Stage Floating Covers	Heated	2.0			
Hall (58)	Minneola, N. Y.	Primary and Activated	Single Stage Fixed Covers	80°	3.0			
Dodge (33)	Ann Arbor, Mich.	Primary and Activated	Single or Two Stage Floating Covers	Heated	3.0	1.3	15	63.1
Larson (110)	Springfield, Ill.	Primary and Activated	Single Stage Floating and Fixed Covers	80°	4.4	0.74	6.51	65.6
Johnson (93)	Belgrave, N. Y.	Primary	Single Stage Hardinge	85°		0.6–2.0		
Marshall (114)	Geneva, N. Y.	Primary	Single Stage	82.4°		1.5		
Andersen (2)	Rockeville Center, N Y.	Primary and Activated	Single Stage Fixed Covers	78°	3.0			38.0

Miscellaneous.—A Roeder bio-reduction plant was put into practical application at Davidson, North Carolina (4). It is claimed that "the impurities removed from this sewage are put through a stabilizing process whereby the animal residues are converted to vegetable-like residue within 10 days because the organic matter which is grown is microscopic, of the order of yeast cells which grow and multiply very rapidly." Description of the nature of the process is not clear and it is difficult to substantiate claims from the report.

Imhoff (89) described a process of hot fermentation of raw sludge for fertilizer production practiced at Frankfort A.M., Germany, which appears similar to the practice in Atlantic City. Sludge from settling tanks is dried to 60 to 70 per cent moisture content and placed in piles, where bacterial fermentation takes place liberating heat (60 to 80° C.) and within 2 to 3 weeks a dry fermented sludge is obtained. The whole process takes 6 to 7 weeks. The percentage of organic matter in dry solids decreases from 59 to 43.2 per cent. The product has about 6 to 12 per cent moisture and 2.02 per cent nitrogen. Odors are produced during the fermentation but the sludge is inodorous.

Mechanical Development

There have been numerous descriptions of mechanical developments, some quite new, while others have been evolved from experience over a period of years but only recently reported.

As a result of such experience, Johnson (94) (95) (96) reports that the new Calumet plant of Chicago Sanitary District will use considerable amounts of alloy metal. For corrosion resistance alone stainless clad metal is specified, but where abrasion may be a factor, solid stainless steel is used of 18–8 (18 per cent chrome, 8 per cent nickel). For resisting high heat as well as corrosion and abrasion in parts of the sludge-burning equipment an alloy of 23 per cent chromium and 8 per cent nickel, with a maximum of 0.25 per cent carbon, is specified.

High chrome, high carbon steel has been used successfully for metalizing worn pump impellers to a Brinell hardness of 400. The cost of such repair has been ⅛ to ¼ of that for a new impeller.

Experience has also been responsible for the design of equipment with high-ratio helical gear reduction, and motors only large enough to develop safe working stresses in the equipment. Shear pins have thus been eliminated. The motors have overload protection.

New plants built during the year are characterized by their effective use of mechanical equipment. Hansen (59) states, that at Buffalo economy of space dictated the use of vertical pumps with motors mounted directly on the pump castings. There are six of these pumps, each of 100 m.g.d. capacity. Two of the pumps have two-speed motors, giving flexibility in operation. An explosion-proof sewer inlet chamber is provided. Grit chambers are mechanically cleaned. Automatic screens discharge into "Triturators." Five 6,000 lb. per day chlorinators are provided. Contact is obtained in the sedimentation tanks.

This plant has an extensive ventilation system with fans in several buildings exhausting to aduct in the piping tunnel and finally discharging to an outer annular ring of the incinerator stack.

Streander (162) described the Niagara Falls plant as an unusual one to serve an unusual condition. Unusual amounts of industrial wastes were claimed to preclude the use of any of the standard treatment methods. River conditions required only partial treatment. Fine screening was adopted but with special provisions for applying a thin mat of coke breeze to the screen surface, thus producing a screen filter for dry weather flows. For storm flows the mat is removed. The screenings plus coke are pneumatically ejected to storage tanks supplied with multiple zone incinerators. The screened or filtered effluent is chlorinated.

Ventilation for safety and odor control has been given considerable attention at St. Paul-Minneapolis as described by Schroepfer and Wilbur (148). At Laguna Beach, Cal., according to Woodward (185), air is exhausted from covered tanks and discharged through chlorinated water sprays to a ventilation tower on a hillside above the plant.

Of importance in connection with fully mechanized treatment plants is an understanding of measuring and recording instruments. DeArman (32), Richardson (133) and Hartley (61) have described such equipment for measuring and recording air, gas or sewage flow, for transmitting such measurements, and of measuring small sewage flows with the fairly new "Kennison Nozzle."

Considerable equipment for sewage treatment has been adapted in the past from equipment designed for metallurgical work and now we have, according to Nichols and Tolman (124), a device for washing grit, adapted from the coal industry. This device, as tested at Indianapolis, reduced putrescible matter 85 per cent, yielding grit containing about 1 per cent putrescible matter, using about 4.5 pounds of water to one pound of feed. The washed grit had little or no odor and seemed unobjectionable.

Specially designed centrifuges have been tested for concentrating excess activated sludge prior to digestion. Kraus and Longley at Peoria, Ill. (105), found it possible to reduce the volume 80 per cent, and returned only 3.5 to 6.5 per cent of the total solids handled to the aeration units by way of centrifuge effluent. Sludge was reduced from one per cent solids to five per cent solids at the rate of 1,824 gallons of one per cent sludge per hour. The sludge had to be screened through a 30-mesh screen and the machine had to be shut down four times daily to clean the bowl. Centrifuges have been installed at Columbus, Ohio, for concentration of sludge prior to digestion. Difficulties have prevented continuous operation.

Donaldson (34) has reported experiences with a large capacity centrifuge for dewatering coarse and fine screenings, grit and sludge. Yields of 700 to 800 lbs. dry solids per hour were obtained against a guarantee of 500. Cake contained 68 to 70 per cent moisture against a guarantee of 65 per cent. Digested sludge of 9 per cent solids yielded

700 lbs. per hour of 50 per cent moisture cake. There was approximately 2 per cent solids in the effluent. Donaldson suggested chemical precipitation for the effluent.

Transite pipe for sewage has gained some favor. Drury (37) states that no difficulty was encountered in laying 1,600 ft. of 16 in. pipe and obtaining tight joints at Ypsilanti, Mich.

Considerable valuable information has been given on the installation and operation of gas engines. Donaldson and Liebman (35) have contributed data on the Coney Island installation. This has produced sufficient power for all purposes. Varying the speed of the engine changes the current frequency, and thus the capacity of the sewage pumps, to correspond with the flow. It has been found that approximately 26 cu. ft. of gas produces one kilowatt hour, or 17 cu. ft., one B.H.P. Cost of operation and maintenance were not given.

At Kokomo, Ind., Miller (118) reports an annual saving of $1,800 per year on a $3,000 engine installation. Here, 30 cu. ft. of gas produces one K.W.H.

Niles (125) at Toledo, O., is so satisfied with the present installation of over 600 H.P. in two engines that a third and larger units is contemplated. The annual savings is computed to be $13,000 on the $38,000 installation.

Industrial Wastes

Increasing interest in the problem of industrial waste disposal has resulted in an unusually large number of papers. The general aspects of the problem are discussed by Weston (178) and by Herndon and Withrow (75), who report the progress made in New England and West Virginia, respectively. Recent developments in the treatment of several wastes are reviewed by Darby and Knowles (30). A general paper on British practice, and on recent industrial waste investigations of the Water Polution Research Board, has been given by Parker (130). Grevemeyer (54) reports extensive agricultural use of various wastes in Europe. The effect of industrial wastes on fish and shellfish is the subject of a paper by Fisher (43).

According to Eldridge (40), the significance of the biochemical oxygen demand test is somewhat doubtful for many industrial wastes, since the values obtained vary with dilution and seeding. The variation is due to an initial inhibition period, which may necessitate incubation periods longer than five days.

Milk Plant Wastes.—The consensus of a number of papers dealing with milk plant waste is that the most promising lines of attack on the problem are reduction of losses within the plant itself, and the treatment of the waste by low or high rate trickling filters or by the Guggenheim biochemical process. Agar (1), after reviewing the various treatment methods in use, favors the trickling filter, and recommends pre-treatment by trickling filters or chemical precipitation if discharge of milk waste to a sewer system exceeds 10 per cent of the sewage flow. Trebler, Ernsberger, and Roland (168) stress the possi-

bilities of conservation within the plant, which, they indicate, will often permit direct discharge of the remaining waste into streams and sewers. They report the chemical cost for the Guggenheim process plants at Glen Karn, Ohio, and Marshall, Indiana, to be $1.00 and $1.60 per day, respectively, for daily flows of 6,000 to 15,000 gallons. Successful use of the activated sludge process at New Bremen, Ohio, and Sommerset, Pennsylvania, is noted. They also describe experiments on high rate trickling filters using tin cans as a filter medium. A three-stage tin-can filter operated at 16 m.g.a.d. appeared to give the best results. The application of the Guggenheim process to milk waste is described in detail by the research staff of Guggenheim Brothers (57).

Eldridge (38) reports satisfactory experiments on the use of the Guggenheim process. Best results were obtained when the waste was kept fresh, the pH maintained at 7.4 to 7.8 and the concentration of solids in the aeration tank held at 2,000 to 3,000 p.p.m. The B.O.D. reduction obtained was 89.3 per cent. In the same bulletin, experiments on high rate filters with both continuous and fill-and-draw recirculation, at total rates of 20 or more m.g.a.d., showed B.O.D. reduction of 85 to 90 per cent when the waste was recirculated 8 to 12 times. Eldridge considers the fill-and-draw recirculating filter particularly suitable for small plants; he (39) gives plans and specifications for construction of standard low rate filters for milk waste treatment.

Davis (31) describes English experiments on milk waste, including a novel system of controlled aerated fermentation, followed by sedimentation of precipitated fat and casein, and by treatment of the effluent on a trickling filter. Leviton and Leighton (111) have developed a process for extracting with alcohol lactose and proteins from spray-dried whey.

Textile Waste.—Hedgepeth and Griffin (70) discuss the general nature of the textile waste problem, emphasizing the possibilities of changes within the plant to reduce or eliminate certain wastes. Snell (155) describes two methods of treating rayon boil-off wastes, the first involving precipitation of the soaps by calcium chloride, with filtration of the sludge, and the second, filtration through a 3 ft. bed of ashes. Dyehouse wastes are successfully treated by coagulation with lime and copperas, followed by sand filtration, according to Schinman and Ruth (145). Fassina (42) describes French methods for dye-waste treatment, including electrolysis with iron or aluminum electrodes and the use of porous adsorbing materials such as treated wood. Béha (11) advocates treatment of dye wastes by passing them, while hot, through charcoal filters, and then coagulating with a mixture of aluminum, copper and ferric sulfates.

Packinghouse Waste.—A valuable paper by Milling and Poole (120) deals with the operation of the activated sludge plant of the Kuhner Packing Company, at Muncie, Indiana. The treatment consists of preaeration, sedimentation, spiral-flow aeration with activated sludge for 11 to 22 hours, and final clarification. Air consumption was 4.25 cu. ft. per gallon of waste, and operating cost $0.55 per hog unit packed. The

effluent had an average B.O.D. of 9 p.p.m., corresponding to 98.8 per cent removal. Each hog unit packed produced 560 gallons of waste, containing 3.14 lb. of B.O.D. Paunch manure and skimmings were disposed of separately on farm land.

Carollo (26) describes a plant built at Phoenix, Arizona, to treat a combination of meat packing, molasses, soap manufacturing, and distillery wastes, with some domestic sewage. Treatment consists of chemical precipitation with ferric chloride made from iron and chlorine. Grease recovery, use of sludge-digestion gas at the molasses plant, and irrigation of land with the effluent are expected to offset treatment costs.

Beet Sugar Waste.—According to Oeming (127) treatment of beet sugar plant wastes by screening and sedimentation in large ponds, although commonly used, is unsatisfactory, since the effluents impart odors to surface water supplies. Eldridge (40) reports full scale experimentation on a treatment plant which comprises grit removal, coagulation of the factory waste with the waste from the Steffens process and sedimentation. The sludge is conditioned with lime and dewatered by vacuum filtration. The reduction of suspended solids and B.O.D. were 95.9 and 54.7 per cent, respectively. The process is regarded as promising, although the effluents still contain 200 to 400 p.p.m. of B.O.D. The report is discussed by Loreaux.

Eldridge and Theroux (41) have continued the study of spray drying of Steffens waste. Clogging of the spray nozzles appears to be the only obstacle to the development of the process.

Cannery Waste.—Experimental work on the coagulation of beet, tomato, and squash canning waste by the use of lime and ferric chloride is reported by Eldridge (40). Good removal of suspended solids and fair B.O.D. removal was obtained, except in the case of the squash waste. Pea cannery waste is treated by screening, coagulation with copperas and lime, and sedimentation, according to Warrick (173).

Distillery Waste.—Complete recovery of distillery wastes by the new Hiram Walker process is described in papers by Boruff and Miller (19), and Cooley (29). The chief difference between this and older recovery processes lies in the centrifuging of the screened slop, which permits the remaining liquid to be concentrated to 45 to 50 per cent solids. Darby and Knowles (30) mention a treatment process which consists of heating the slop at high pressures, thus producing a rapid settling and filtering sludge.

Pulp and Paper Waste.—Developments in recovery of by-products from sulfite pulp waste include the manufacture of vanillin and guaiacol, and of ligninphosphate, which is used as a scale preventive and remover for boiler waters. Production of vanillin, yeast, and tall-oil is described by Tomlinson (167). Schroeder, Berk, and O'Brien (146) report the use of sulfite waste liquor as a preventive of caustic embrittlement in boilers. Grevemeyer (55) states that sulfite liquors and wash waters from the soda and sulfate processes may be mixed with sewage or clarified white-waters and used for irrigation.

Brecht and Scheufelen (20) describe the use of Sveen size solution in conjunction with flotation save-alls to recover 90.6 to 99.3 per cent of the pulp in white waters. Air or other gases blown into white-waters carry the pulp to the surface, from whence it is easily removed, according to Karlström (99). Operation of the ADKA save-all, which recovers fibre and filler from white-waters by flotation, is described by Darby and Knowles (30).

Gas and Coke Plant Wastes.—A method for complete disposal of ammonia liquor from coal gas retorts consists of passing the ammonia and water vapor from the retorts through glowing coke. Stief (160) reports that the hydrogen thus liberated is used as fuel for the retorts. Effluent water from producer gas plants is de-phenolized by treatment with magnesium and sodium chlorides, followed by electrolysis, according to Taganov and Novodereshkin (166).

Iron Pickling Liquors.—An extensive symposium on the regeneration of pickling liquors, with numerous contributors, was published in the periodical *Stahl und Eisen.* Most of the processes described consist of batch or continuous crystallization of ferrous sulfate, with return of the mother liquor to the pickling process. Sierp and Fränsemeier (151) utilize partially dehydrated ferrous sulfate ($FeSO_4.H_2O$) as an aid to crystallization. Heimberger (73) describes a process using dilute acid (0.1 per cent) at 70° C. as the pickling medium, the dissolved iron flocculating as ferric hydroxide. No waste is produced, the hydroxide being removed and the acid made up to strength as required. Rinsing water is re-used.

Stoof (161) describes a process for treating pickling waters in which the liquor is oxidized, the ferric salt solution thus obtained is clarified and returned to the pickling vats and the precipitated iron compounds are used for the manufacture of pigments. Ferron, a material produced from the slurry formed by treating pickling liquors with lime, is described in the August issue of *Chemical and Metallurgical Engineering.* It is claimed to be an excellent insulating and building material, which is plastic at one stage of manufacture, and can therefore be molded into any desired shape. Chlorinated spent pickling liquors have been used at Akron, Ohio, as coagulants for the water treatment plant. The acid content of the liquors proved helpful when the raw water was high in alkalinity, according to Gettrust and Hostetter (51).

Tannery Waste.—Milligan (119) states that the methods in use in Pennsylvania for treating tannery wastes include sedimentation of mixed wastes, holding of tan liquors for periods of high stream flow, and treatment by means of trickling filters, preceded by chemical precipitation if necessary. For tanneries discharging to sewers, two stage sedimentation tanks holding one day's flow are recommended.

Fassina (42) suggests removal of sodium chloride from tannery wastes with spent zeolite, mixing the effluent with waters containing soap to precipitate the lime, and removal of sulfides by electrolysis with iron electrodes.

Mine Wastes and Oil Field Brines.—Bleed water, the corrosive hot water produced in the Frasch process of sulfur mining, may be returned to the process if its corrosiveness is mitigated. This may be done by aerating, according to Burns and Smith (22), or by treatment with hydrated lime, trisodium phosphate, or disodium phosphate and barium chloride, according to McIver, Chatelain and Axelrad (115).

Oil field brine disposal in Louisiana is discussed by Fuelbhardt (45); and in Michigan by Oeming (127), who states that ponding of the brines does not prevent them from reaching the streams, and recommends returning them to underground formations.

Miscellaneous.—Wastes from the production of fish meal are treated by sedimentation, by evaporation, or by the removal of fat, according to Jordan (97). Lanninger (109) describes the disposal of the effluent from a potato starch factory by spraying on land, while Bartow and Walker (10) report recovery of inositol and other valuable chemicals from the steep water from corn starch plants. Waste waters from glass factories, containing polishing rouge, are clarified with milk of lime, according to Scheuring and Liebmann (144).

At the Lawrence Experiment Station of the Massachusetts State Health Department, laundry wastes have been successfully treated with ferric sulfate. The B.O.D. reduction is 87 per cent. Sludge is dried on sand beds.

At the Dow Chemical Company plant in Midland, Michigan, Harlow, Powers and Ehlers (60) reported that phenolic wastes were treated in a plant consisting of a clarifier and trickling filters. This plant reduces the phenol content of the waste from 20 or 30 p.p.m. down to 0.5 p.p.m. The filters may be ripened with river water, which contains phenol-destroying organisms.

Effect of Industrial Wastes on Sewage Treatment

Industrial wastes are apparently being handled at sewage plants in larger volumes and with fewer difficulties than in former years. Some operators have even come forward with statements regarding helpful effects of certain industrial wastes on sewage treatment processes.

Sedimentation, Chlorination.—At the Gulvin Park Sewage plant in Geneva, New York, Marshall reports difficulty with beet cannery waste, even though the waste had been subjected to screening at the cannery. The quantities of grit, settleable solids and B.O.D. in the sewage were increased, and the sewage had an abnormally high color. Unusually high chlorine dosages were required for maintenance of residuals in the plant effluent during the period of operation of the cannery.

An informal discussion conducted by Snow (156) at the N. E. S. W. A. Spring Meeting brought out several interesting experiences with industrial wastes at New England sewage plants. At Greenwich, Connecticut, photographic developers rendered the maintenance of chlorine residuals difficult, but laundry wastes were found to aid sludge digestion

by maintaining proper pH in the digesters. At New Haven, bleaching wastes chlorinated the sewage at times without cost to the city. At South Norwalk, paper mill wastes helped to clarify a sewage containing silk mill wastes and to produce a better-drying sludge.

At the Medina, Ohio, plant, according to Orford and Scharch (128), a canning factory producing pickles and relishes was responsible in part for a high solids load, which resulted in rising sludge in the sedimentation tanks, and the production of bad odors. Application of activated carbon proved beneficial in checking both conditions.

Gehm (49) states that industrial wastes, especially those containing acid, have been helpful in producing flocculation in sewage at New Brunswick. The pH of the mixed sewage and waste was about 4.0. The settled effluent contained only 12 to 22 p.p.m. suspended solids.

Hauck (68) cites experience with iron pickling wastes at Cleveland. These wastes appear to travel through sewers as a slug, without undergoing much dilution. Quantities which are small relative to the total sewage flow may therefore suffice to upset a treatment plant.

Sludge Digestion.—Haseltine (63) reports that packing plant wastes have in the past caused difficulty with sludge digestion at Topeka. The new plant design therefore provided for three-stage digestion, with mixing equipment in the first stage tank for breaking up scum. Scum formation, however, has persisted in the new digesters, despite the mixing equipment. It is believed that this may be due to the high grease content of the packing house wastes.

Trickling Filters.—Husman (88) reports the successful treatment on a trickling filter of a mixture of 19 parts of sewage, and one part of waste from a plant producing benzine by hydrogenation of coal.

Activated Sludge.—Dodge (33) experienced difficulty at Ann Arbor with wastes containing copper salts. The copper compounds increased the suspended solids in the aeration tanks, and seriously retarded the development of new activated sludge.

Miles and Porges (116) (117) treated mixtures of sulfur dye waste and domestic sewage by the activated sludge process on a semi-plant scale. Variations in the amount of air supplied had little effect on the removal of B.O.D. and color. The rate of aeration, however, did affect the removal of suspended solids. The reduction in suspended solids increased with increased periods of aeration up to six hours, with little additional removal up to nine hours. Color removal seemed to be almost directly proportional to the concentration of suspneded solids carried in the aeration tank. Beyond about 3,000 p.p.m. of suspended solids, no improvement in color removal was noted.

In Greensboro, N. C. (53), a new activated sludge plant has been designed to treat 6.5 m.g.d., of which 2.0 m.g.d. are textile wastes. The plant is very flexible, permitting more than twelve different combinations in use of equipment. It will be possible to add chlorine, iron salts, alum or carbon at the entrance to the flash mixers, as well as to the aeration or final settling tanks.

At the Calumet works of the Chicago Sanitary District, iron from pickling waste has produced on the diffuser plates a deposit of ferric oxide, which has caused serious plugging of the plates. Coarse limestone laid over the plates to a depth of 4 to 6 inches has curbed the deposition of the oxide. At present, the wastes are excluded from the sewers, and their use as a sludge conditioner, in conjunction with chlorine, is being investigated.

Haseltine (63) reports that packinghouse waste containing blood has produced rising sludge in the secondary clarifiers of the Topeka activated sludge plant. The rising is similar to that experienced at Sioux Falls, and is believed to be due to the formation of nitrogen gas. Packing plant grease, and grease and oil of mineral origin, have caused heavy scums on the primary clarifiers, and have, at times, entered the aerators in quantities sufficient to upset the activated sludge process.

Stream Pollution

The increasing interest in stream pollution as a national problem resulted in the passage, by both the House of Representatives and the Senate, of the Barkley-Vinson Bill, which provided for federal and state co-operation in stream pollution control. The bill, however, failed to become a law, being vetoed by the President because there was no provision in it for review, by the executive branch of the federal government, of the projects which an engineering board of control was authorized to recommend for the receipt of federal aid in the form of loans and grants. A revised form of the Barkley-Venson Bill has been presented during the present session of Congress, and, if passed, should stimulate both research in stream pollution and a co-ordinated program of pollution control.

Progress has been made in the formation of interstate compacts on some of the main drainage basins. The Ohio River Valley Water Sanitation Compact has been drafted and approved by the commissioners of the participating states and is to be submitted to their legislatures for ratification. This compact provides for a supervisory commission composed of three appointees from each state. It binds the signatory states to:

> faithful co-operation in the control of future pollution in and abatement of existing pollution from the rivers, streams and waters in the Ohio River Basin which flow through, into or border upon any of such signatory States, and in order to effect such object, agrees to enact any necessary legislation to enable each such State to place and maintain the waters of said basin in a satisfactory sanitary condition, available for safe and satisfactory use as public and industrial water supplies after reasonable treatment, suitable for recreational use, capable of maintaining fish and other aquatic life, free from unsightly or malodorous nuisances due to floating solids or sludge deposits, and adaptable to such other uses as may be legitimate.

Under this compact, a minimum treatment required of effluents discharging into such interstate streams would be removal of at least 45 per cent of suspended solids.

Using a somewhat different procedure the Interstate Delaware Commission, comprising the four states of Delaware, New Jersey, New York

and Pennsylvania, recently entered into a reciprocal agreement for pollution control in the Delaware River Basin. This agreement was ratified by the New York and New Jersey legislatures, and was worked out by the state health departments of the four states concerned. The agreement divides the Delaware River system into four zones of decreasing standards of cleanliness from the headwaters to the Atlantic Ocean. The minimum standards of Zone 4, which is the lowest portion of the stream, provide, among other things, for a reduction of at least 55 per cent of the total suspended solids in effluents discharging into the stream, absence of noticeable floating solids, oil and grease and germicidal treatment of the effluent when the discharge is near shellfish grounds or recreational areas. Prior to the discharge of effluents into Zone 1, the clean headwater areas, there are required among other things, 85 per cent B.O.D. removal, a maximum B.O.D. of 50 p.p.m. and a maximum of 5 per cent depletion of the D.O. content of the receiving stream. *B. coli* in the effluent are limited to 100 per c.c. in any sample and 90 per cent of the samples must show less than 1 per c.c.

In a discussion of the application of British standards for sewage effluents, Garner (47) stressed the unfavorable effects, under certain conditions, of bypassing stormwater flows in excess of six times the dry weather flow of sewage. He cited instances during the recent drought in which streams were in good condition during extreme low water, when the total sewage flow was being treated, but stream quality deteriorated and fish were killed after short periods of rainfall when excess storm water was discharged without treatment.

Of major interest is the completion of the program for elimination of the most serious points of pollution in the Great Lakes drainage basin, sewage treatment plants having been completed at Niagara Falls, Detroit, Buffalo and Cleveland during the past year.

Deoxygenation and Reaeration.—With the wide range of sewage treatment processes available, from which it is possible to select almost any desired degree of treatment, a more exact determination of the capacity of a stream for self purification becomes of prime importance in order to utilize economically this tremendous natural resource. Velz (169) presented a theoretical study of deoxygenation and reaeration based largely upon Phelps' diffusion formula. The paper presents an interesting approach to this highly complex problem, but one which needs extensive trial on actual river data for its proper evaluation. In a later paper the same author (170) gives, briefly, the results of a recent study of pollution of the Hudson River. In this latter paper are shown dissolved oxygen profiles for the Hudson under present and under assumed conditions of one-third reduction of pollution such as would be obtained by primary treatment of tributary sewage.

In a series of reaeration measurements in a closed channel with circulation induced by propellers, Kehr (102) found the reaeration rate of tap water was progressively decreased by the addition of sewage, the severity of the effect being also dependent upon the velocity of flow. Additions of 0.5 per cent and 2 per cent sewage reduced the reaeration

rate to about two-thirds that of tap water when recirculated at velocities 10 ft. per minute or above, but had little effect on the reaeration rate when velocities were 5 ft. per minute or less.

An excellent example of the practical application of reaeration calculations was presented by Wisely and Klassen (182) in their study of the Illinois River between Peoria and Beardstown. These authors estimated the rate of reaeration by the "oxygen balance" method in a stretch of the river where sludge deposits were absent and by applying the rate found to the stretch immediately below Peoria, obtained a value for the deoxygenating effect of the sludge deposits in this latter section. Using Streeter and Phelps' "oxygen sag" formulation, they obtained excellent correlation between theoretical and observed D.O. values and concluded that critical conditions during low flows were largely due to sludge deposits which contributed 50 per cent of the total oxygen demand load of 526,000 lb. per day. The permissible pollution at Peoria which would give a minimum D.O. content of 4 p.p.m., if sludge deposits had been eliminated, was estimated to be 292,000 lb. of 20-day B.O.D. per day.

Sludge Deposits.—Several papers dealing with sludge deposits have appeared during the past year. Baity (6) reported the results of a series of experiments in which sludge was placed in 20-liter sealed carboys. The overlying water was continuously replaced, the demand of the sludge deposits being computed by summation of the difference between influent and effluent oxygen contents. Baity concluded that the demand of a thin layer of sludge, .089 cm., was essentially satisfied after 36 days at 21.2° C. In other experiments, the oxygen content of the overlying water was found to have no consistent effect on the oxygen demand. Sunlight had no effect on the demand or on biological content and the salinity of the overlying waters had an inverse linear relationship with the oxygen demand. With increases in depth up to 4 cm., the demand Y of a sludge was best expressed by an exponential relationship,

$$Y = 2700\ X^{.485} \text{ mgs. per day per sq. m.,}$$

where X was the depth of the sludge in centimeters. The increase in rate of demand with increasing temperature checked well with Phelps' formula for temperature effect on biochemical reactions.

Rudolfs (140) in experiments with fresh and activated sludges, stored in open carboys up to 400 days, obtained with fresh sludge about 65 per cent reduction of volatile matter and 95 per cent reduction of B.O.D. after 400 days. Replacement of the supernatant water gave a more rapid reduction in B.O.D. of the sludge up to 130 days. The supernatant water had a high demand during the early part of the experiment, but this decreased to 3.5 p.p.m. at the end of 400 days.

In an extensive investigation of the hydraulic properties of silt and sludge deposits in the estuary of River Mersey, the Water Pollution Research group (175) of the British Department of Scientific and Industrial Research concluded that there was no appreciable difference

in the organic contents of mud from the upper estuary of the Mersey and that from the Irish Sea and various unpolluted estuaries in the British Isles, and that the crude sewage discharged into the Mersey estuary had no effect on the amount and hardness of the deposits in the estuary.

Wasar, Husmann and Blöchliger (174) studied a stretch of the Limmat River polluted by settled sewage from the City of Zurich for a year prior and a year following construction of an impounding reservoir which extended from 5 to 11.5 miles below the point of entrance of Zurich sewage. Decreased aeration, together with sedimentation in the reservoir, particularly by masses of sewage fungi which underwent acid fermentation, left the stream in worse condition than before construction of the reservoir when it was a rapidly flowing stream. The authors divide sludge into three categories: (1) A fine sludge derived from sewage, (2) a secondary sludge which is similar in character to domestic sewage sludge, but which has its origin in decomposition of *Sphaerotilus* growths and (3) mineral sludge carried in by high water. It was found that a distance of 8 stream miles were required to completely mix Zurich sewage with Limmat water.

Stream Surveys.—Viehl (171) reported the results of two and a half years' study of the Elster impounding reservoir above Leipzig. He found that B.O.D. reductions averaged 45 per cent in winter and 44 per cent in summer when the presence of plankton tended to raise the B.O.D. At 0° C., B.O.D. reduction was 30 per cent. Decomposition of phenols was lower in winter, but the nitrite content of the effluent was higher, because of decreased utilization of the nitrates by plant life. Total bacteria counts were higher in winter due to the decrease of bacteria-eating plankton.

In a study of the Scioto River (Ohio) plankton, Lackey (106) described a rapid convenient method of counting plankton, which consisted of centrifuging 100 to 200 c.c. of river water and examining an aliquot portion, 1/20 to 1/24 c.c., of the concentrate spread uniformly under a 25 mm. square cover glass. He found that preserving specimens with formalin did not reduce total counts much, but did affect many of the characteristics necessary for identification. In another paper, the same author (107) lists at length the protozoa found during a year of study of the Scioto River. Certain species were tentatively suggested as indicators of pollution.

Industrial Waste Pollution.—Oeming (127) summarized methods used in Michigan to control pollution from waste oil field brines. In the Crystal Oil field 1,000 to 5,000 barrels per day are being returned to underground formations by gravity through dry holes or abandoned wells. Brine wastes from the Dow Chemical Company plant at Midland, which processes 45,000 barrels of brine daily for bromine, are handled largely by storage and rapid discharge during periods of maximum dilution, with provision being made for operation of water plants on stored water while these slugs of brine pass waterworks intakes downstream.

Hawley (69) described the use of periodic flushing with stored water for the elimination of sludges of industrial origin in a stream near Fort Worth, Texas. During the year ending August 31, 1937, a total of 97 days flushing were required, 400 to 500 c.f.s. being released for several days at a time.

In a study of the decline of the oyster industry of the York River, Virginia, Galtshoff and his co-workers (46) could find no changes in natural conditions which would account for the decline in quality of oysters from the river. The river was polluted by paper mill wastes and it was found that in the presence of black liquor from the paper-mills, the rate of feeding of the oysters was reduced and growth was stunted. The oysters quickly recovered when placed in unpolluted sea water.

Fisher (43) pointed out the many ways in which industrial wastes affect shellfish and fin fish. A river purifies itself more quickly from sewage pollution than from certain industrial wastes which may affect fish for much greater distances. Industrial wastes may decrease the oxygen content, add acid, alkalinity, salt or turbidity, blanket the bottom, be highly toxic, indirectly decrease the growth rate by decreasing food supplies or impart tastes to certain food fish.

In a study of the biology of streams polluted by acid mine wastes, Lackey (108) found a decrease in numbers and types of organisms present as compared with unpolluted streams in the same locality, but found certain species abundant at pH values as low as 1.8.

Smith (154) reported destruction of fish life in a tributary of the upper Columbia River by cyanides which had leached out of a mine refuse pile containing 1.21 pounds of sodium cyanide per ton.

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STUDIES OF SEWAGE PURIFICATION

IX. TOTAL PURIFICATION, OXIDATION, ADSORPTION AND SYNTHESIS OF NUTRIENT SUBSTRATES BY ACTIVATED SLUDGE

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The first phenomenon taking place when a nutrient substrate such as sewage is aerated with activated sludge has been described (Parsons,[1] Theriault,[2] Heukelekian,[3] and others) as the clarification stage. The term clarification has been defined as the removal of carbonaceous and nitrogenous organic matter in all states of dispersion (suspension, colloidal and true solution) from the substrate by the sludge as a result of coagulation, adsorption and other mechanisms. A number of theories to explain the mechanism of clarification have been proposed and have been recently reviewed by Theriault.[2] Theriault[4, 5, 6] has also proposed a new biozeolitic theory. These theories will not be discussed here. The clarification process is generally considered to be very rapid, equilibrium being reached in 30 to 40 minutes. This stage is followed by what has been described as reactivation, or restoration of the powers of clarification. The present paper is a further presentation of the results of a study of clarification and reactivation phenomena of the activated sludge process.

In three earlier papers[7, 8, 9] of this series, data upon the oxidation rates of nutrient substrates aerated with activated sludge during the clarification stage have been obtained by the "difference" method. In these papers data were presented on the rate of reduction of the biochemical oxygen demand of the organic matter in the substrates that resulted during portions of the first 24-hour aeration period with activated sludge. The studies showed definitely that rates of biochemical oxidation of substrates by activated sludge are much higher than the rates obtained normally in polluted streams or in dilution bottles. The tremendous bacterial populations containing oxidation enzymes, present and active, when fresh nutrient substrates are mixed with activated sludge was proposed as the explanation of the high rates of biochemical oxidation that are observed.

It is the purpose of this paper to present data on the total removal of biochemical oxygen demand (B.O.D.) of nutrient substrates by activated sludge and to show what portion of the total removal may be accounted for by oxidation. The demonstration of the portion of the total B.O.D. removal that is the result of oxidation has not been made before. The removal of organic matter as measured by the reduction of the total carbonaceous oxygen demand (L value) of the substrate will be defined here as the total B.O.D. removal or total purification. The quantity of oxygen utilized by the sludge-nutrient substrate mixture as a result of the addition of the substrate (as has been described[8, 9]), is

defined as the B.O.D. of the substrate removed by oxidation. The difference between the total B.O.D. removal and the oxidation of the substrate will be referred to here as the net adsorption and synthesis. It should be understood, however, that the term net adsorption and synthesis is used simply for convenience and that this term includes also any B.O.D. removal accomplished by coagulation, hydrolysis and any possible mechanisms other than oxidation.

Experimental Methods

Sludge.—Data will be presented showing the total purification and oxidation of substrates when aerated in the presence of pure culture and plant activated sludges. The pure culture sludges used were identical with those already described.[8] The plant sludges were obtained from the north side plant at Lancaster, Pa., and from the experimental plant at this station.

Nutrient Substrates.—Synthetic sewage of the composition given in an earlier paper [8] of this series was used in experiments with both pure culture and plant activated sludge. This material simulated sewage in its biochemical oxygen demand value but had no suspended detritus and contained all of the nutrient material in true colloidal or soluble form. It contained peptone and meat extract as nutrients besides small quantities of urea, disodiumhydrogen phosphate and other inorganic salts usually found in sewage. Domestic sewage filtered through cotton was used in experiments with normal activated sludge and after sterilization also with the pure culture sludge. The domestic sewage was heat sterilized (15 lbs. steam pressure for 20 minutes) when used in experiments with pure culture sludge. Previous experimental work [8] indicated that heat sterilization altered the condition of the sewage less than other sterilization methods and also that this sterilized sewage was as suitable a substrate for activated sludge development as the sewage before sterilization.

Dilution Water.—The quarter strength phosphate buffered [10] (Formula C) water was used for all dilution purposes in these experiments.

General Procedure.—The procedure followed in these experiments has been described in detail.[8] Briefly it consisted of aerating simultaneously and at approximately the same rate, six liters of sludge-nutrient substrate mixtures in one large bottle and a liter of sludge-dilution water mixture and a liter of sludge-nutrient substrate mixture in two separate closed aeration bottles. The total B.O.D. removal was determined by periodic examination of the substrate in the large bottle and the extent of oxidation was followed in the closed bottles.

In order to save the time required to separate the sludge from the supernatant by settling and to reduce the quantity of sample required, each aeration mixture sample taken to determine total B.O.D. removal was first filtered through No. 1 Whatman paper, and diluted portions of the filtrate were then immediately prepared for incubation. This

procedure, used in experiments with synthetic sewage, did not remove any oxidizable material which would not have been removed by settling for the synthetic sewage nutrients were entirely in colloidal and soluble form. In the experiments with cotton filtered sewage it is possible that the procedure may have indicated in some cases a slightly higher organic matter removal than would have been obtained by settling after short periods of aeration.

However, comparative B.O.D. tests on filtered supernatant and supernatant after one hour settling, following 24 hour aeration periods of sterile sewage and synthetic sewage with pure culture activated sludge, indicated that there was very little difference between the two procedures. These computed L values as derived from B.O.D. results at various periods of incubation are tabulated below:

Experiment Number	Substrate Feed	Initial L Value of Substrate		L Value of Substrate after 24 Hours		Percentage Reduction	
		Settled	Filtered	Settled	Filtered	Settled	Filtered
1	Sterile Sewage	279	277	33.7	21.8	87.9	92.1
2	Sterile Sewage	517	513	49.0	56.8	90.5	88.9
3	Synthetic Sewage	—	400	36.7	34.2	90.8	91.5

The filtration procedure was, therefore, adopted for all experiments as being the best method of removing the sludge particles quickly in order to obtain an estimate of the total quantity of nutrient material remaining in the substrate.

Pure Culture Activated Sludge Experiments

The pure culture sludges represent the simplest activated sludge system because they contain the flocs of only one bacterial species and no plankton or protozoa. Accordingly, the data on the experiments performed with pure culture sludge will be presented first. In Table I are presented the basic data of biochemical oxygen demands of the nutrient substrates used in all our experiments with pure culture sludge. The initial B.O.D. of the mixture of nutrient substrate and remaining sludge liquor was calculated from the B.O.D. of the old supernatant removed and the B.O.D. of the nutrient substrate added. The B.O.D. of the supernatant after various periods of aeration was determined by the dilution method. Using the theoretical formula for rate of carbonaceous oxidation of sewage at 20° C. $[y = L\ (1\text{–}10^{-kt})]$ with $k = 0.1$ and each B.O.D. value of the supernatant shown in Table I, an L value or total carbonaceous oxygen demand was calculated. However, B.O.D. observations for long incubation periods, where examination showed nitrification, were not included in calculations of the L value. The means of the L values calculated from all incubation time B.O.D. ob-

servations for the supernatant after each aeration time are shown in Table II.

From the data in Table II, the percentage reduction in the total carbonaceous oxygen demands (L values) of the substrates obtained after various periods of aeration with pure culture sludge, were calculated and are shown in Table III. Curves showing the mean percentage reduction of these L values for the experiments with sterile sewage and with synthetic sewage substrates aerated with pure culture sludge are shown in Fig. 1. Curves showing the maximum and minimum sub-

TABLE I.—*B.O.D. of Supernatants When Nutrient Substrates Are Aerated in the Presence of Pure Culture Activated Sludge*

Experiment No.	Suspended Solids, P.p.m.	Nutrient Substrate	B.O.D. Incubation Period, Days	B.O.D. of Supernatant Liquor After the Indicated Aeration Time in Hours						
				0	½	1½	3	5	10	24
1	1420	Sterile Sewage	2	109.0	59.5	19.8	12.8	12.0		7.9‖
			3	138.0	62.0	23.8	15.2	15.0		10.1‖
			4	164.0	81.0	27.4	17.0	18.0		12.2‖
			5	186.0	97.5	31.8	22.2	19.7		14.9‖
2	1632	Synthetic Sewage	2	174.0	85.0	61.0	22.5	12.5		7.0‖
			3	193.0	114.0	89.0	35.0	23.5		11.2‖
			4	208.0	141.0	103.0	47.5	39.5		15.3‖
			5	228.0	157.0	114.0	51.0	38.5		15.8‖
3	843	Sterile Sewage	2	159.0	67.5	32.2†		18.0‡		8.2
			5	202.0	95.5	46.0†		26.4‡		14.4
			7	242.0	112.0	51.2†		27.2‡		26.0
			11	230.0	100.0	53.7†		32.6‡		28.0
			13	249.0	104.0	63.5†		35.8‡		31.5
4	2644	Sterile Sewage	2	90.0	30.5	19.0	13.0	9.4	9.2	7.2
	—		5	129.0	40.0	—	15.0	13.0	9.6	12.6
			7	130.0	39.0	15.5	20.7	18.4	10.8	13.9
			10	135.0	61.0	27.7	21.0	16.8	16.0	17.6
			15	133.0	60.5	36.5	36.0	24.4	22.0	21.6*
			20	186.0	79.0	39.7	57.0*	31.8	26.0	34.2*
5	1560	Synthetic Sewage	2	113.0	—	28.2	10.0	18.8	19.6	10.3
			5	154.0	66.0	44.5	27.2	22.6	28.0	15.5
			7	172.0	110.0	47.5	28.5	24.8	36.0	17.3
			10	205.0	122.0	51.7	30.7	35.4	37.8	23.3
			15	215.0	120.0	55.0	44.0	39.2	45.0	29.2
			20	305.0	149.0	68.5	42.7	67.6*	43.2	53.8*
6	2428	Synthetic Sewage	2	113.0	78.5	51.5	20.0	13.8	8.0	13.5
			5	154.0	114.0	78.0	31.2	19.6	16.4	20.8
			7	171.0	121.0	74.0	34.5	25.2	21.8	26.0
			10	205.0	133.0	90.5	40.0	18.8	26.0	35.0
			15	214.0	149.0	107.0	51.5	40.4	23.4	78.9*
			20	305.0	165.0	131.0	100.0*	45.0	29.2	161.0*

TABLE I—*Continued*

Experiment No.	Suspended Solids, P.p.m.	Nutrient Substrate	B.O.D. Incubation Period, Days	B.O.D. of Supernatant Liquor After the Indicated Aeration Time in Hours						
				0	½	1½	3	5	10	24
7	1632	Sterile Sewage	2	89.9	27.5	27.0	21.2	17.8	11.2	22.6
			5	129.0	42.5	41.0	27.2	18.0	15.4	26.4
			7	130.0	45.0	39.0	34.0	23.8	19.4	28.7
			10	135.0	55.0	53.0	36.7	33.4	19.6	30.0
			15	132.0	—	57.0	52.7	51.0	19.9	46.4
			20	190.0	—	109.0	85.5	69.6	36.0	81.2
8	1056	Sterile Sewage	2	196.0	88.5	40.5	23.2	17.8	14.6	12.1
			5	289.0	115.0	56.0	35.7	28.0	18.2	19.5
			7	286.0	113.0	64.5	42.2	33.6	22.0	22.8
			10	337.0	124.0	72.0	45.7	37.2	40.0	29.7
			15	358.0	135.0	78.2	49.8	46.2	43.8	30.8
			20	435.0	150.0	85.0	85.0	41.6	46.0	38.2
9	2112	Sterile Sewage	2	196.0	56.5	29.5	18.5	17.2	11.6	9.5
			5	289.0	95.0	51.0	28.0	24.2	17.0	17.0
			7	277.0	96.5	64.5	35.7	24.0	24.0	19.5
			10	336.0	110.0	67.5	39.0	28.6	34.0	18.0
			15	359.0	106.0	73.0	39.5	27.2	34.8	23.9
			20	434.0	140.0	77.5	44.7	33.0	35.4	28.5
10	1112	Synthetic Sewage	2	81.3	65.5	44.5	22.5	18.0§	8.6	13.6
			5	108.0	85.0	65.0	31.2	23.6§	20.6	16.0
			7	123.0	98.0	78.0	36.0	27.8§	24.0	19.0
			10	166.0	105.0	90.0	41.7	29.6§	30.0	22.4
			15	172.0	—	122.5	48.5	41.0§	35.0	24.6
			20	210.0	128.0	102.0	49.7	41.4§	36.4	26.3
11	2232	Synthetic Sewage	2	79.6	43.0	19.5	17.5	8.4	15.0	9.6
			5	106.0	66.0	33.5	21.2	25.0	19.0	11.5
			7	122.0	72.0	40.0	23.7	30.4	20.0	12.8
			10	165.0	85.0	35.0	28.7	35.8	22.0	18.1
			15	170.0	88.5	48.0	38.2	32.0	24.0	18.7
			20	207.0	115.0	53.5	47.5	40.0	35.0	24.7

* Nitrification indicated. † 2 hours. ‡ 4 hours. § 4½ hours. || 22 hours.

strate L value reductions obtained on both sterile sewage and on synthetic sewage are shown in Fig. 2. These curves indicate that the L value of the substrate was removed very rapidly by pure culture activated sludge which had been developed on either sterile sewage or on synthetic sewage. The fact that there is a consistent difference between the curves representing the L value removed in the synthetic sewage and in the sterile sewage experiments may be explained in whole or in part by chemical as well as physical differences between the two substrates, but the possibility cannot be ruled out that part of the observed difference may be a reflection of an unequal response of the sterile sewage and synthetic sewage substrates to the filtration technique.

TABLE II.—*Total Carbonaceous Oxygen Demand (L Value) of Supernatant When Nutrient Substrates are Aerated in the Presence of Pure Culture Activated Sludge*

Experiment No.	*L* Value of Supernatant Liquor Initially and After the Indicated Aeration Time in Hours						
	Initial	½	1½	3	5	10	24
1	279	141	48.4	31.5	30.3	—	20.9§
2	384	231	170.0	71.2	50.7	—	22.5§
3	277	124	64.1*	—	36.4†	—	29.3
4	178	66.7	35.9	28.7	23.9	19.9	18.7
5	251	129	64.0	37.5	38.9	45.2	25.7
6	250	167	115.0	48.1	34.3	25.9	34.6
7	179	63.5	59.9	47.0	38.8	25.9	43.4
8	416	163	86.5	59.3	43.7	38.3	32.2
9	414	131	77.3	44.1	34.2	32.6	24.8
10	184	134	107.0	49.7	39.2‡	31.6	26.8
11	182	101	49.1	37.9	35.1	29.7	20.5

Sterile sewage feed used in Experiments 1, 3, 4, 7, 8, 9.
Synthetic sewage feed used in Experiments 2, 5, 6, 10, 11.
* 2 hours. † 4 hours. ‡ 4½ hours. § 22 hours.

TABLE III.—*Percentage Reduction of Total Carbonaceous Oxygen Demand (L Value) of Supernatants When Nutrient Substrates are Aerated in the Presence of Pure Culture Activated Sludge*

Experiment No.	*L* Value of Initial Supernatant, P.p.m.	Percentage Reduction of *L* Value after Indicated Aeration Time in Hours					
		½	1½	3	5	10	24
1	279	49.5	82.7	88.7	89.1	—	92.5¶
2	384	39.8	55.7	81.5	86.8	—	94.1¶
3	277	55.2	76.9‡	—	86.9§	—	89.4
4	178	62.5	79.8	83.9	86.6	88.8	89.5
5	251	48.6	74.5	85.1	84.5	82.0	89.8
6	250	33.2	54.0	80.8	86.3	89.6	86.2
7	179	64.5	66.5	73.7	78.3	85.5	75.8
8	416	60.8	79.2	85.7	89.5	90.7	92.3
9	414	68.4	81.3	89.3	91.7‖	92.1	94.0
10	184	27.2	41.8	73.0	78.7	82.8	85.4
11	182	44.5	73.0	79.2	80.7	83.7	88.7
Ster. Sew. Avg.*	290	60.2	77.7	84.3	87.0	89.3	88.9
Syn. Sew. Avg.†	250	38.7	59.8	79.9	83.4	84.5	88.8

* Sterile sewage feed used in Experiments 1, 3, 4, 7, 8, 9.
† Synthetic sewage feed used in Experiments 2, 5, 6, 10, 11.
‡ 2 hours. § 4 hours. ‖ 4½ hours. ¶ 22 hours.

However, it is believed that future research will probably show that most of the difference may be ascribed to the chemical and physical differences between the two substrates. It will be noted from Table III and Figs. 1 and 2, that the total purification was less rapid with synthetic sewage, that is, in a substrate in which all of the nutrient material was in colloidal or true solution.

As the larger suspended particles would be removed from sewage by filtration through paper, the sewage purification, as illustrated by these

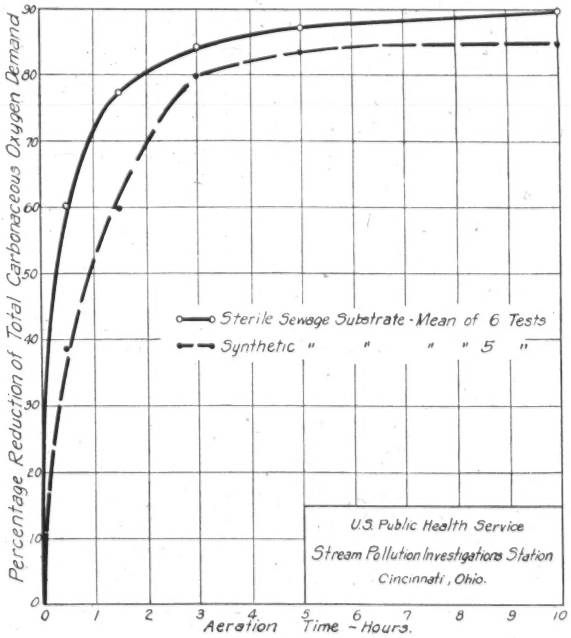

FIG. 1.—Total purification of nutrient substrates aerated in the presence of pure culture activated sludge.

curves, might be criticized as being too rapid due to the filtration employed to separate the supernatant from the sludge before the B.O.D. tests were made. It has been shown [3, 11] that suspended matter is easily removed by aeration of sewage followed by sedimentation and more easily by aeration in the presence of activated sludge. Also, as stated previously, comparative tests on supernatants after filtration and after settling showed no material differences. It is believed, therefore, that the filtration, introduced to quickly separate the sludge, did not alter materially the B.O.D. removal results in the experiments employing normal sewage.

The quantities of oxygen used to oxidize the nutrient substrates in the experiments with pure culture sludge are shown in Table IV. The method of obtaining these data has been described [8] in detail and need not be repeated here. Table V shows the data of Table IV computed to percentages of the initial L values of the supernatant. These results represent the proportion of the substrate L values oxidized in successive periods. In Fig. 3 are representative curves illustrative of the rate of reduction of the L value of the substrate produced by oxidation. It should be noted that between 27 and 40 per cent of the L value of the

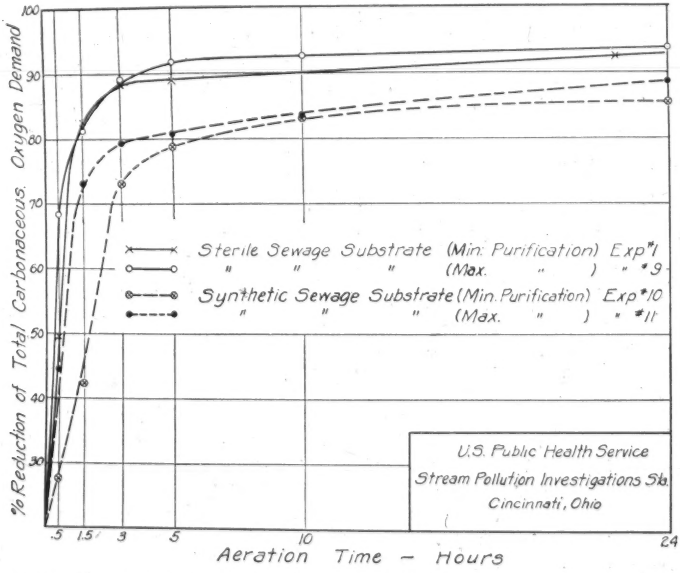

FIG. 2.—Representative curves showing total purification of nutrient substrates aerated in presence of pure culture activated sludge.

substrate has been oxidized in 5 hour's aeration and that these figures increase to about 40 to 60 per cent at the end of 24 hours. This shows that with these activated sludge systems, a greater proportion of the L value of the substrate was satisfied in the first 5 hours than is satisfied in the first day under normal biochemical oxidation (20.5 per cent with a k of 0.1 at 20° C.).

Purification by Oxidation.—When the percentages of the L value of the substrates that are oxidized as given in Table V, are divided by the corresponding percentages of total purification, as given in Table III, the fractions of the total purification that have been accomplished by oxidation are obtained. The results of these computations are shown

in Table VII. The mean percentage of the total carbonaceous purification that is accomplished by oxidation for the synthetic and sterile sewage experiments are plotted in Fig. 4. These data indicate that, with pure culture activated sludge (developed by one species of bacteria rather than a grossly mixed culture) an average of 16 and 21 per cent

TABLE IV.—*Quantities of Oxygen Used to Oxidize the Nutrient Substrate When Aerated in the Presence of Pure Culture Activated Sludge*

Experiment No.	Initial L Value of Supernatant, P.p.m.	Milligrams of Oxygen Used per Liter in Indicated Time in Hours					
		½	1½	3	5	10	24
1	279	24.8	47.5	63.8	75.3	—	111.9§
2	384	31.0	79.3	106.9	121.0	—	158.3§
3	277	20.7	54.4*	—	75.5†	—	159.3
4	178	21.3	40.7	56.7	52.0	75.8	107.9
5	251	22.7	56.8	77.8	94.5	105.8	115.3
6	250	12.3	38.3	63.0	83.8	99.5	155.8
7	179	20.4	40.9	46.3	64.4	74.8	103.9
8	416	29.7	63.2	86.7	118.0	166.4	233.0
9	414	48.6	72.4	102.9	130.1	158.4	193.2
10	184	27.0	40.8	53.3	67.2‡	86.3	95.6
11	182	24.7	47.8	63.6	74.5	83.5	84.2

* 2 hours. † 4 hours. ‡ 4½ hours. § 22 hours.

of the L value removed during the first half hour was the result of oxidation. These percentages increased rapidly and at the end of 5 hours, an average of about 35 and 43 per cent, respectively, of the total purification of sterile sewage and of synthetic sewage was the result of oxidation. The data definitely indicate that biochemical oxidation is a

TABLE V.—*Percentage of the Total Carbonaceous Oxygen Demand (L Value) of the Nutrient Substrate Oxidized When Aerated in the Presence of Pure Culture Activated Sludge*

Experiment No.	Percentage Oxidized in the Indicated Time in Hours					
	½	1½	3	5	10	24
1	8.9	17.0	22.9	27.0	—	40.1§
2	8.1	20.7	27.8	31.5	—	41.2§
3	7.5	19.6*	—	27.3†	—	57.5
4	12.0	22.9	31.9	29.2	42.6	60.6
5	9.0	22.6	31.0	37.6	42.2	45.9
6	4.9	15.3	25.2	33.5	39.8	62.3
7	11.4	22.8	25.9	36.0	41.8	58.0
8	7.1	15.2	20.8	28.4	40.0	56.0
9	11.7	17.5	24.9	31.4	38.3	46.7
10	14.7	22.2	29.0	36.5‡	46.9	52.0
11	13.6	26.3	34.9	40.9	45.9	46.3

* 2 hours. † 4 hours. ‡ 4½ hours. § 22 hours.

factor of major importance to the clarification stage of these activated sludge systems.

Net Adsorption and Synthesis.—As the percentage of the *L* value of the substrate that has been removed and the percentage that has been

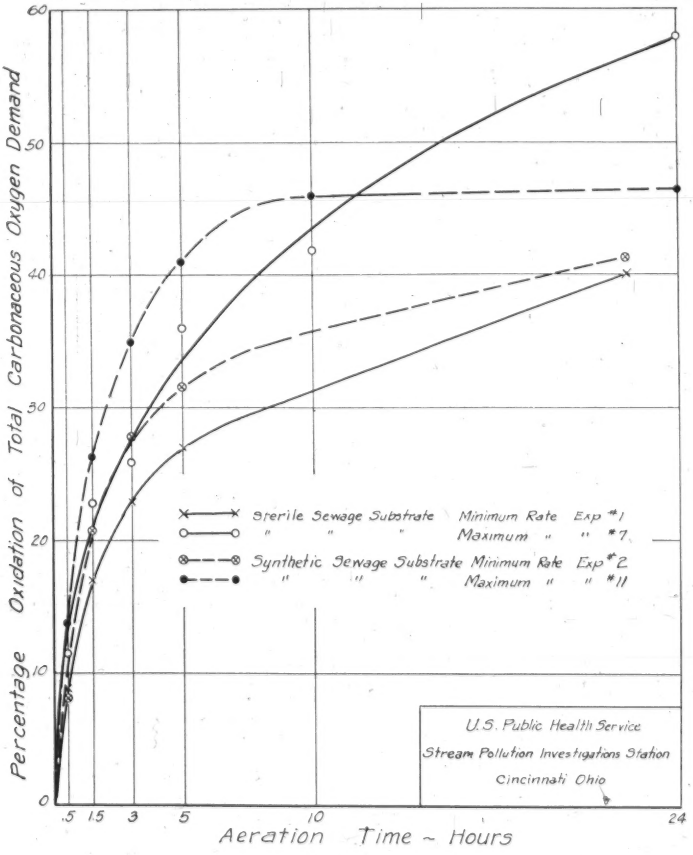

FIG. 3.—Representative curves showing oxidation of nutrient substrates aerated in presence of pure culture activated sludge.

oxidized are given in Tables III and V, respectively, it is necessary only to subtract the percentages in the latter table from the corresponding percentages in the former to obtain an estimate of the percentages of purification that were the result of net adsorption and synthesis. The

net percentages of the L value of the substrate that is removed by adsorption and synthesis, computed in this way, are shown in Table VI. In Figs. 5 and 6 are shown the total purification, oxidation and net

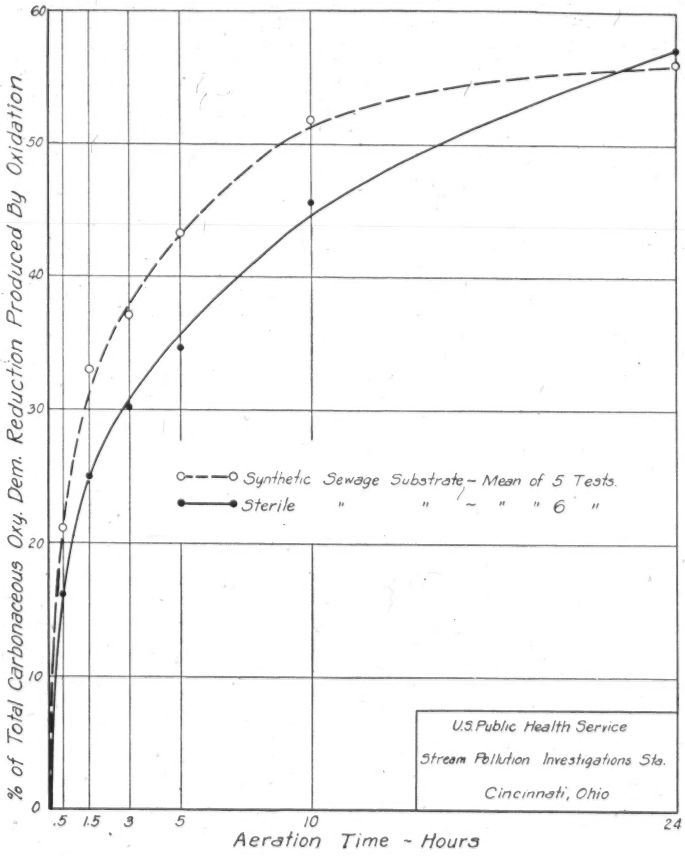

FIG. 4.—Percentage of total carbonaceous oxygen demand reduction produced by oxidation of nutrient substrates aerated with pure culture activated sludge.

adsorption and synthesis curves for experiments 9 and 11 with sterile sewage and with synthetic sewage respectively. These two figures illustrate the proportions of the total purification assignable to oxidation and to net adsorption and synthesis which may be expected to occur during the first ten hours of aeration with pure culture sludges. Fig. 7

TABLE VI.—*Net Percentage of the Total Carbonaceous Oxygen Demand (L Value) of the Nutrient Substrate that is Removed by Adsorption and Synthesis When Aerated in the Presence of Pure Culture Activated Sludge*

Experiment No.	Nutrient Substrate Used	Net Percentage Removed by Adsorption and Synthesis in Indicated Time in Hours					
		½	1½	3	5	10	24
1	Sterile Sewage	40.6	65.7	65.8	62.1	—	52.4
3	" "	47.7	57.3*	—	59.6†	—	31.9
4	" "	50.5	56.9	52.0	57.4	46.2	28.9
7	" "	53.1	43.7	47.8	42.3	43.7	17.8
8	" "	53.7	64.0	64.9	61.1	50.7	36.3
9	" "	56.7	63.8	64.4	60.3	53.8	47.3
Mean	Sterile Sewage	50.4	58.6	59.0	57.1	48.6	35.8
2	Synthetic Sewage	31.7	35.0	53.7	55.3	—	52.9§
5	" "	39.6	51.9	54.1	46.9	39.8	43.9
6	" "	28.3	38.7	55.6	52.8	49.8	23.9
10	" "	12.5	19.6	44.0	42.2‡	35.9	33.4
11	" "	30.9	46.7	44.3	39.8	37.8	42.4
Mean	Synthetic Sewage	28.6	38.4	50.3	47.4	40.8	39.3

* 2 hours. † 4 hours. ‡ 4½ hours. § 22 hours.

TABLE VII.—*Percentage of the Total Carbonaceous Oxygen Demand Reduction of the Substrate Actually Oxidized When Aerated with Pure Culture Activated Sludge*

Experiment No.	Substrate Feed Used	Percentage Oxidized in the Indicated Aeration Time in Hours					
		½	1½	3	5	10	24
1	Sterile Sewage	18.0	20.6	25.8	30.3	—	43.4¶
3	" "	13.6	25.5‡	—	31.4§	—	64.3
4	" "	19.2	28.7	38.0	33.7	48.0	67.7
7	" "	17.7	34.3	35.1	46.0	48.9	76.5
8	" "	11.7	19.2	24.3	31.7	44.1	60.7
9	" "	17.1	21.5	27.9	34.2	41.6	49.7
Mean	Sterile Sewage	16.2	25.0	30.2	34.6	45.6	57.2†
2	Synthetic Sewage	20.4	37.2	34.1	36.3	—	43.8¶
5	" "	18.5	30.3	36.4	44.5	51.5	51.1
6	" "	14.8	28.3	31.2	38.8	44.4	72.3
10	" "	54.0	53.1	39.7	46.4‖	56.6	60.9
11	" "	30.6	36.0	44.1	50.7	54.8	52.2
Mean	Synthetic Sewage	21.1*	33.0*	37.1	43.3	51.8	56.1

* Excluding No. 10.
† Excluding No. 7.
‡ 2 hours. § 4 hours. ‖ 4½ hours. ¶ 22 hours.

shows the mean net adsorption and synthesis curves for sterile and for synthetic sewage aerated with pure cultures.

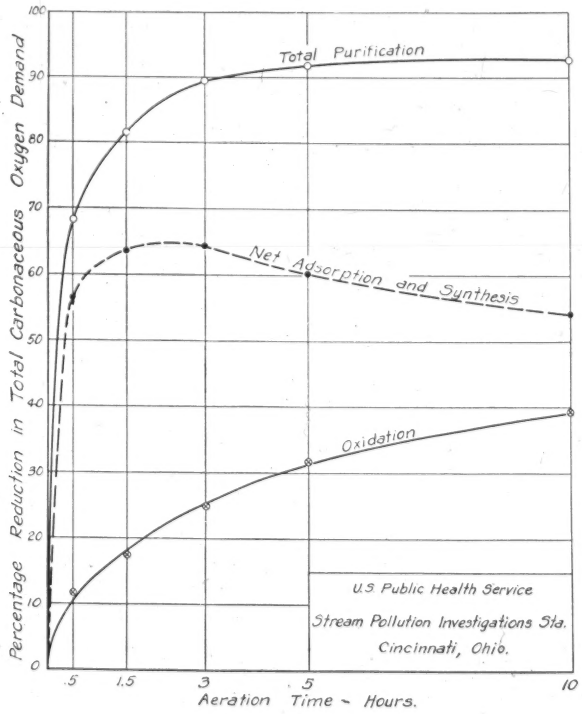

FIG. 5.—Representative curves showing reduction of total carbonaceous oxygen demand of sterile sewage substrate aerated with pure culture activated sludge. (Exp. No. 9.)

NORMAL ACTIVATED SLUDGE EXPERIMENTS

The experiments with normal (*i.e.* grossly mixed cultures) activated sludge were conducted in exactly the same way as those with pure culture sludge. Activated sludge from the north plant at Lancaster, Pa., was used in the first eight experiments. Experiment 9 consisted of a series of tests made on sludge from our experimental plant during the development of activated sludge. The details of experiment 9 have been described [9] and need not be repeated.

The base data showing the biochemical oxygen demands of the supernatants in this series of experiments are given in Table VIII. The mean total carbonaceous oxygen demands (L values) were calculated from the data in Table VIII in the manner described above. These cal-

culated data are presented in Table IX. The percentages of reduction of the total carbonaceous oxygen demands were calculated as for the pure culture experiments. These percentages are shown in Table X.

The quantities of oxygen used to oxidize the nutrient substrates in these experiments are given in Table XI. With these quantities and the initial total carbonaceaus B.O.D. (L value) of the substrate the percentages of the L value oxidized were calculated as shown in Table XII.

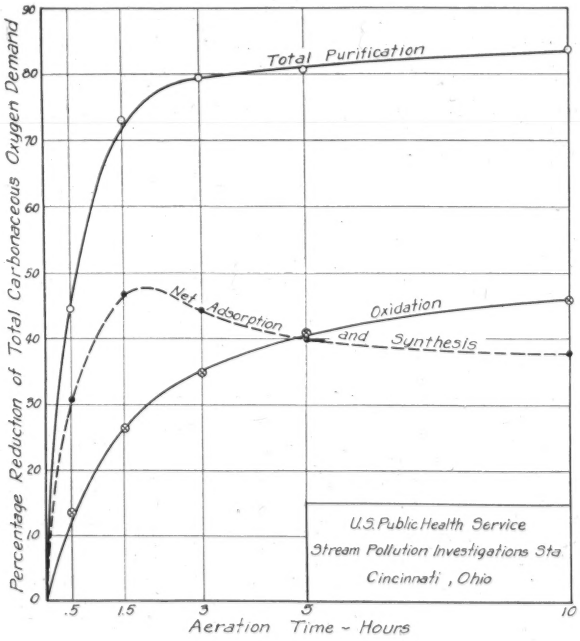

FIG. 6.—Representative curves showing reduction of total carbonaceous oxygen demand of synthetic sewage substrate aerated with pure culture activated sludge. (Exp. No. 11.)

The asterisks in Tables XI and XII indicate that in experiments 4, 8 and 9–S9, nitrification of the substrate was underway at the completion of the experiments when examinations for nitrite and nitrate were made. As examinations for nitrite and nitrate had not been made earlier it is not possible to tell when the nitrification began. It seems reasonable to assume that in these three experiments with actively nitrifying activated sludge that the nitrification of the substrate began between the first and third hour of aeration. Consequently the oxidation values given in Table XI for these experiments should be reduced by the quantity of oxygen required to produce the nitrites and nitrates

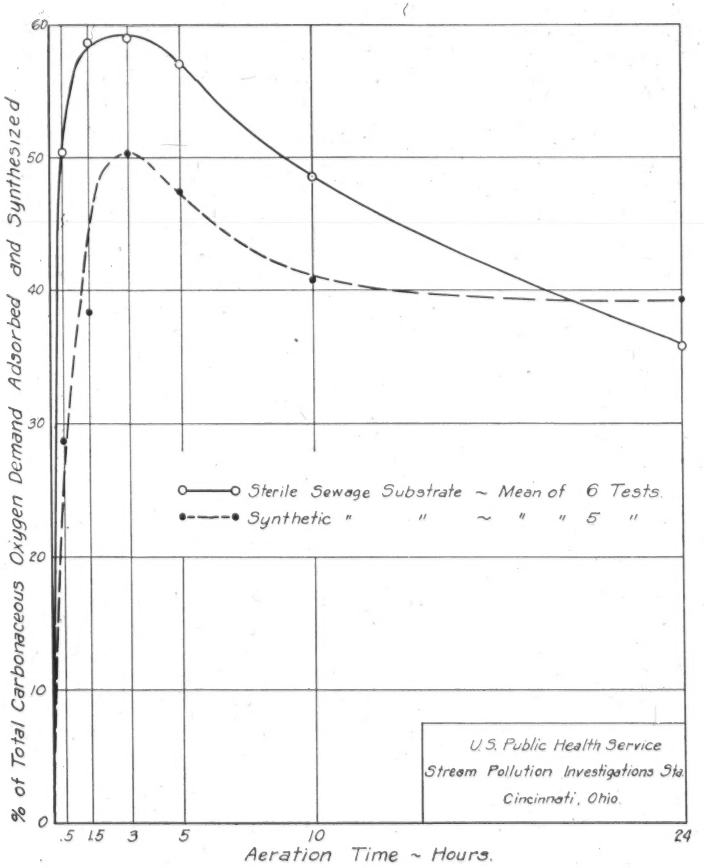

FIG. 7.—Net percentage of total carbonaceous oxygen demand (L value) of nutrient substrates removed by adsorption and synthesis when aerated in presence of pure culture activated sludge.

present, as the observations on total purification were confined to the carbonaceous stage. Corrections for nitrification could not be made in these experiments because of the lack of the intermediate nitrite and nitrate data. The results of these experiments are retained to demonstrate the wide differences in the purification obtained under these conditions even though the total purification and oxidation in such cases may not be strictly comparable. This complication did not enter into the pure culture sludge experiments because the cultures employed were incapable of oxidizing ammonia nitrogen. In all of the normal activated sludge experiments, except the three mentioned above, nitrites and nitrates were not found in the substrate at the completion of the aeration period and consequently all of the oxygen was utilized in oxi-

TABLE VIII.—*B.O.D. of Supernatants When Nutrient Substrates Are Aerated in the Presence of Normal Activated Sludge*

Experiment No.	Suspended Solids, P.p.m.	Nutrient Substrate	B.O.D. Incubation Period, Days	B.O.D. of Supernatant Liquor After the Indicated Aeration Time in Hours (Parts Per Million)						
				Initial 0	½	1½	3	5	10	24
1	4610	Settled Sewage	3	132	32.4	15.1	8.8	9.2	5.8	4.5
			5	162	42.8	24.0	13.0	10.7	8.0	11.7
			7	168	49.6	32.6	17.1	13.0	9.0	13.6
			10	200	62.0	40.0	21.4	15.8	14.0	13.8
2	1000	Settled Sewage	3	189	124.0	73.6	56.5		19.3	10.5
			5	251	152.0	82.0	84.0		29.0	12.0
			7	296	173.0	111.0	188.0		32.8	12.6
			10	394	209.0	150.0	139.0		41.1	21.1
3	2448	Settled Sewage	2	96.6	24.8	15.6	6.2	6.1	5.0	6.9
			5	142.0	42.0	28.3	17.4	6.8	8.8	6.0
			7	155.0	48.0	29.1	17.0		13.8	10.8
			10	171.0	123.0	77.3	62.5	50.0	21.4	
			15	244.0	169.0	132.0	94.0	64.8	40.6	25.2
			20	352.0	189.0	137.0		69.6	34.6	25.0
4	2504	Clarified Sewage	2	47.6	11.4	10.8	2.3	2.0	3.5	8.3
			5	67.0	19.6	24.9	6.4	7.8	6.0	8.7
			7	77.4	61.6	40.0	25.5	15.0	15.2	13.0
			10	80.6	59.0	60.6	38.0	33.5	15.9	
			15	132.5	135.0	88.6	75.9	51.8	23.5	28.9
			20	186.6	155.0	109.2		54.0	24.5	19.8
5	2812	Synthetic Sewage	2	160	111.0	95.2	80.0	70.0	26.9	14.4
			5	257	172.0	161.0	140.0	124.0	62.5	22.0
			7	297	206.0	188.0	182.0	145.0	86.2	32.5
			10	322	253.0	234.0	190.0	195.0	119.4	58.9
			15	336	390.0	323.0		221.0	152.0	75.2
			20	384	449.0				157.0	80.7

TABLE VIII.—*Continued*

Experiment No.	Suspended Solids, P.p.m.	Nutrient Substrate	B.O.D. Incubation Period, Days	B.O.D. of Supernatant Liquor After the Indicated Aeration Time in Hours (Parts Per Million)						
				Initial 0	½	1½	3	5	10	24
6	2676	Synthetic Sewage	2	182	162.0	112.0	95.0	74.0	27.6	6.7
			5	268	220.0	171.0	149.0	123.0	47.6	13.0
			7	280	239.0	195.0	176.0	168.0	55.4	12.0
			10	311	260.0	220.0	289.0	246.0	74.8	18.5
			15	335	399.0	393.0	298.0	264.0	142.0	49.7
			20	547	465.0	402.0	377.0	309.0	163.0	62.0
7	2268	Settled Sewage	2	159	60.0	23.8*		13.6†	9.1	4.6
			5	235	96.0	36.8*		21.7†	10.3	10.5
			7	250	110.0	46.0*		31.7†	17.0	11.3
			10	264	128.0	92.0*		58.0†	32.1	9.3
			15	282	227.0	162.0*		91.8†	35.0	27.2
			20	381	276.0	180.0*		97.1†	44.9	28.5
8	3564	Settled Sewage	2	53.7	18.2	8.6*		14.8†	6.0‡	8.0
			5	96.8	27.5	10.8*		20.0†	10.9‡	10.0
			7	106.0	35.7	22.4*		18.6†	14.0‡	11.9
			10	122.0	42.5	37.4*		35.0†	18.0‡	13.0
			15	125.0	52.0	33.2*		31.4†	18.5‡	14.9
			20	124.0	118.5	46.2*		30.4†	18.7‡	15.0
9–S1	182	Settled Sewage	2	60.6	51.5	37.5*		26.0†		10.1
			5	114.3	80.0	59.5*		31.7†		13.6
			7	164.3	101.0	60.5*		35.0†		19.3
			10	165.5	105.0	72.0*		71.2†		20.5
			15	216.3	100.0	89.5*		60.7†		34.6
			20	264.5	158.0	115.0*		97.5†		70.3
9–S3	760	Settled Sewage	2	129	10.0	13.5*				6.2
			5	234	32.0	46.0*		26.0†		17.0
			7	200	78.0	66.0*		38.5†		18.0
			10	219	80.0	40.5*		21.0†		21.8
			15	285	107.0	25.0*		64.5†		
			20	415	253.0	138.0*		169.0†		
9–S4	1188	Settled Sewage	5	57.5	24.0	13.6*		11.8†		13.4
			7	63.7	51.0	14.0*		22.6†		15.5
			10	64.5	40.0	24.0*		21.0†		21.7
			15	96.8	42.5	16.8*				
			20	126.0	76.5					
9–S5	1462	Settled Sewage	2	54.5	30.5	10.6*		9.8†		5.2
			5	125.0	44.5	15.6*		11.4†		9.4
			7	140.0	52.5	21.0*		15.6†		16.2
			10	148.0	65.5	24.2*		26.6†		24.0
			15	148.0	93.0	43.0*		35.8†		
			20	177.0	94.0	62.0*				

TABLE VIII.—*Continued*

Experiment No.	Suspended Solids, P.p.m.	Nutrient Substrate	B.O.D. Incubation Period, Days	B.O.D. of Supernatant Liquor After the Indicated Aeration Time in Hours (Parts Per Million)						
				Initial 0	½	1½	3	5	10	24
9–S6	1448	Settled Sewage	2	51.9	16.0	12.7*		18.8†		3.0
			5	83.6	31.5	23.2*		22.0†		7.5
			7	99.6	26.5	24.0*		21.0†		9.8
			10	113.0	40.5	42.5*		24.2†		
			15	121.0	46.5			44.8†		11.2
			20	129.0	66.0			52.8†		15.1
10–S8	2920	Settled Sewage	2	135.0	10.0	13.0*		9.0†		8.0
			5	182.0	17.5	16.5*		16.8†		13.4
			7	225.0	29.0	26.2*		23.4†		15.0
			10	266.0	29.0	24.2*		27.2†		17.8
			15	306.0	55.5	29.2*		30.2†		16.8
			20	336.0	76.0	35.2*		31.2†		22.8
10–S9	2864	Settled Sewage	2	147	18.5§		17.8	8.8		8.5
			5	144	25.5§		29.0	14.6		12.7
			7	231	34.5§		30.5	22.2		14.4
			10	228	36.0§		32.0	23.6		15.5
			15	231	39.0§		37.0	27.4		19.4
			20	251	51.5§		41.5	26.8		18.9

* 2 hours. † 4 hours. ‡ 12 hours. § 1 hour.

TABLE IX.—*Total Carbonaceous Oxygen Demand (L Value) of Supernatant When Nutrient Substrates are Aerated in the Presence of Normal Activated Sludge*

Experiment No.	Activated Sludge Suspended Solids, P.p.m.	*L* Value of Supernatant Liquid Initially and After the Indicated Time in Hours						
		0	½	1½	3	5	10	24
1	4610	234	64.6	37.6	20.4	17.0	12.5	14.6
2	1000	388	230.0	144.0	130.0		42.0	19.4
3	2448	214	62.9	40.0	21.1	13.2	14.6	13.7
4	2504	103	50.6	45.8	22.4	18.2	15.2	14.5
5	2812	385	273.0	247.0	215.0	184.0	90.8	37.3
6	2676	395	337.0	260.0	232.0	197.0	74.2	18.2
7	2268	334	150.0	69.4*		43.2†	24.2	13.1
8	3564	135	47.0	34.8*		32.4†	18.0‡	16.0
9–S1	182	189	121.0	87.4*		60.5†		23.6
9–S3	760	296	74.0	51.4*		36.5†		22.1
9–S4	1188	83.8	46.8	20.4*		22.9†		21.0
9–S5	1462	165	76.4	29.8*		25.9†		18.7
9–S6	1448	128	43.1	36.4*		36.5†		10.7
9–S8	2920	305	35.7	29.8*		27.9†		19.4
9–S9	2864	287	43.8		40.7	25.8†		19.3

Settled sewage feed used in Experiments 1, 2, 3, 7, 8 and 9.
Clarified sewage feed used in Experiment 4.
Synthetic sewage feed used in Experiments 5 and 6.
* 2 hours. † 4 hours. ‡ 12 hours.

TABLE X.—*Percentage Reduction of Total Carbonaceous Oxygen Demand (L Value) of Supernatants When Nutrient Substrates are Aerated in the Presence of Normal Activated Sludge*

Experiment No.	*L* Value of Initial Supernatant	Percentage Reduction of *L* Value After Indicated Time in Hours					
		½	1½	3	5	10	24
1	234	72.4	83.9	91.4	92.7	94.7	93.8
2	388	40.7	62.9	66.5		89.2	95.0
3	214	70.6	81.3	90.1	93.8	93.2	93.6
4	103	50.9	55.5	78.3	82.3	85.2	85.9
5	385	29.1	35.8	44.2	52.2	76.4	90.3
6	395	14.7	34.2	41.3	50.1	81.2	95.4
7	334	55.1	79.2*		87.1†	92.8	96.1
8	135	65.2	74.2*		76.0†	86.7‡	88.1
9–S1	189	36.0	53.8*		68.0†		87.6
9–S3	296	75.0	82.6*		87.7†		92.5
9–S4	83.8	44.2	75.7*		72.7†		74.9
9–S5	165	53.7	81.9*		84.3†		88.7
9–S6	128	66.3	71.6*		71.5†		91.6
9–S8	305	88.3	90.2*		90.9†		93.6
9–S9	287	84.7		85.8	91.0†		93.3

Settled sewage used in Experiments 1, 2, 3, 7, 8 and 9.
Clarified sewage used in Experiment 4.
Synthetic sewage used in Experiments 5 and 6.
* 2 hours. † 4 hours. ‡ 12 hours.

TABLE XI.—*Quantities of Oxygen Used to Oxidize the Nutrient Substrate When Aerated in the Presence of Normal Activated Sludge*

Experiment No.	Initial *L* Value of Supernatant	Milligrams of Oxygen Used per Liter in Indicated Time in Hours					
		½	1½	3	5	10	24
1	234	13.9	46.9	81.0	134.2	161.5	173.8
2	388	3.9	26.7	47.7		122.2	176.3
3	214	8.3	24.0	50.4	75.1	101.7	
4	103	22.0	44.1	80.7	107.3	124.4*	
5	385	8.2	36.6	54.1	71.4	121.4	130.0
6	395	18.8	45.5	71.0	89.8	139.0	184.6
7	334	7.1	41.2‡		88.7§	145.6	189.8
8	135	25.2	49.7‡		106.7§	155.9‖	213.7*
9–S1	189	0.0	7.3‡		16.0§		46.6
9–S3	296	16.4	39.0‡		49.0§		86.4
9–S4	83.8	0.4	10.0‡		13.8§		16.4
9–S5	165	21.2	34.8‡		42.6§		121.7
9–S6	128	20.5	36.5‡		45.6§		94.6
9–S8	305	47.0†		84.8	92.8		89.2
9–S9	287	29.1†		137.3	158.6		226.4*

Settled sewage used in Experiments 1, 2, 3, 7, 8 and 9.
Clarified sewage used in Experiment 4.
Synthetic sewage used in Experiments 5 and 6.
* Substrate was being nitrified.
† 1 hour. ‡ 2 hours. § 4 hours. ‖ 12 hours.

TABLE XII.—*Percentage of the Total Carbonaceous Oxygen Demand (L Value) of the Nutrient Substrate Oxidized When Aerated in the Presence of Normal Activated Sludge*

Experiment No.	Percentage Oxidized in the Indicated Time in Hours					
	½	1½	3	5	10	24
1	5.9	20.0	34.6	57.4	69.0	74.3
2	1.0	6.9	12.3		31.5	45.4
3	3.9	11.2	23.6	35.1	47.5	
4	21.4	42.8	78.3	104.1	120.8*	
5	2.1	9.5	14.1	18.5	31.5	33.8
6	4.8	11.5	18.0	22.7	35.2	46.7
7	2.1	12.3		26.6§	43.6	56.8
8	18.7	36.8‡		79.0§	115.5‖	158.3*
9–S1	0.0	3.9‡		8.5§		24.7
9–S3	5.5	13.2‡		16.6§		29.2
9–S4	0.5	11.9‡		16.5§		19.5
9–S5	12.8	21.1‡		25.8§		73.8
9–S6	16.0	28.5‡		35.6§		73.9
9–S8	15.4†		27.8	30.4		29.2
9–S9	10.1†		47.8	55.2		78.9*

Settled sewage used in Experiments 1, 2, 3, 7, 8 and 9.
Clarified sewage used in Experiment 4.
Synthetic sewage used in Experiments 5 and 6.
* Substrate was being nitrified.
† 1 hour. ‡ 2 hours. § 4 hours. ‖ 12 hours.

TABLE XIII.—*Net Percentage of the Total Carbonaceous Oxygen Demand (L Value) of the Nutrient Substrate that is Removed by Adsorption and Synthesis When Aerated in the Presence of Normal Activated Sludge*

Experiment No.	Nutrient Substrate Used	Net Percentage Removed by Adsorption and Synthesis in Indicated Time in Hours					
		½	1½	3	5	10	24
1	Settled Sewage	66.5	63.9	56.8	35.3	25.7	19.5
2	" "	39.7	56.0	54.2		57.7	49.6
3	" "	66.7	70.1	66.5	58.7	45.7	
7	" "	53.0	66.9†		60.5‡	49.2	39.3
8	" "	46.5	37.4†		0.0‡	0.0§	0.0
4	Clarified Sewage	29.5	12.7	0.0	0.0	0.0	0.0
5	Synthetic Sewage	27.0	26.3	30.1	33.7	44.9	56.5
6	" "	9.9	22.7	23.3	37.4	46.0	48.7
9–S1	Settled Sewage	36.0	49.9†		59.5‡		62.9
9–S3	" "	69.5	69.4†		71.1‡		63.3
9–S4	" "	43.7	63.8†		56.2‡		55.4
9–S5	" "	40.5	60.8†		58.5‡		14.9
9–S6	" "	50.3	43.1†		35.9‡		17.7
9–S8	" "	72.9*		62.7	60.5‡		64.4
9–S9	" "	74.6*		38.0	35.8‡		14.4

* 1 hour. † 2 hours. ‡ 4 hours. § 12 hours.

dizing carbonaceous material. In these experiments, therefore, the total purification and oxidation data are as comparable as in the pure culture sludge experiments.

The net percentages of the L value of the substrate removed by adsorption and synthesis (obtained as above for pure culture sludges) are given in Table XIII. The percentages of L value removal accom-

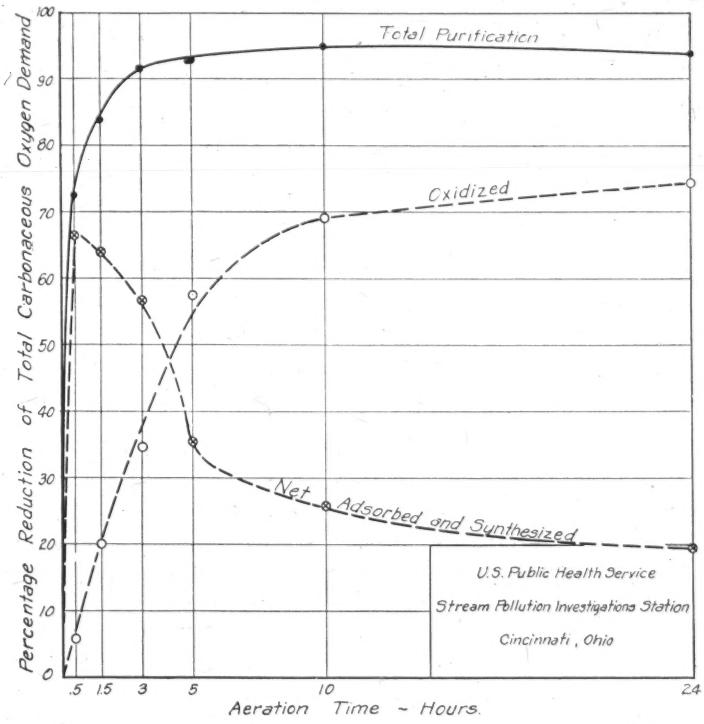

FIG. 8.—Reduction of total carbonaceous oxygen demand (L value) of settled sewage substrate aerated with activated sludge. Experiment 1. 4610 p.p.m. normal activated sludge. Initial substrate L value = 333 p.p.m.

plished by total purification, by oxidation and by net adsorption and synthesis for a number of experiments with normal activated sludge have been plotted in Figs. 8 to 13. For this presentation the experiments were selected to illustrate the effects of some of the factors which influence the purification mechanism.

In Experiment 1 a sewage with an L value of 233 p.p.m. was aerated with a sludge of 4610 p.p.m. of suspended solids. The results plotted in Fig. 8 show that total purification was very rapid, 72.4 per cent of

the L value being removed in 0.5 hour and over 90.0 per cent in 3 hours. The L value reduction produced by oxidation was 5.9 per cent in 0.5 hour. This rapidly increased to 57.4 per cent in 5 hours. The net adsorbed and synthesized results reached a maximum of about 66.5 per cent in 0.5 hour and then dropped rapidly, falling below the percentage oxidized after about 4.0 hours. After 24 hours 74.3 per cent of the L

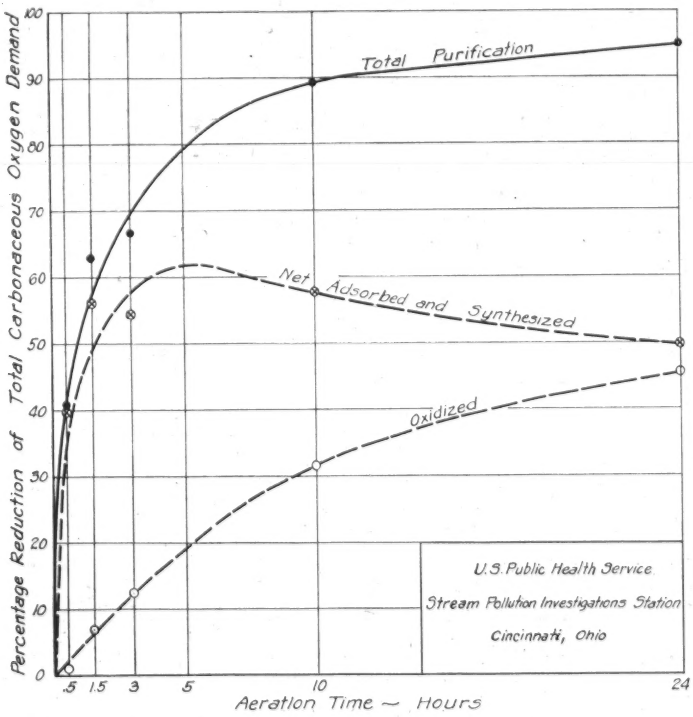

FIG. 9.—Reduction of total carbonaceous oxygen demand (L value) of settled sewage substrate aerated with activated sludge. Experiment 2. 1000 p.p.m. normal activated sludge. Initial substrate L value = 389 p.p.m.

value had been oxidized and only 19.5 per cent remained as adsorbed and synthesized material. As it seems reasonable that most of the biochemical synthesis accompanying bacterial multiplication had been completed before the 24 hour period, and that such synthesis might be estimated at from 5 to 10 per cent of the L value, this would leave 9.5 to 14.5 per cent of the material removed from the substrate still absorbed or coagulated in the sludge after 24 hours. The results of experiment 1, just discussed, illustrate the activated sludge purification

mechanism when a large quantity of non-nitrifying activated sludge is given a normal quantity of nutrient substrate.

The results of experiment 2 illustrate the mechanism of purification when a small quantity of activated sludge (1000 p.p.m. suspended solids) is dosed with a substrate having a rather high (389 p.p.m.) L value.

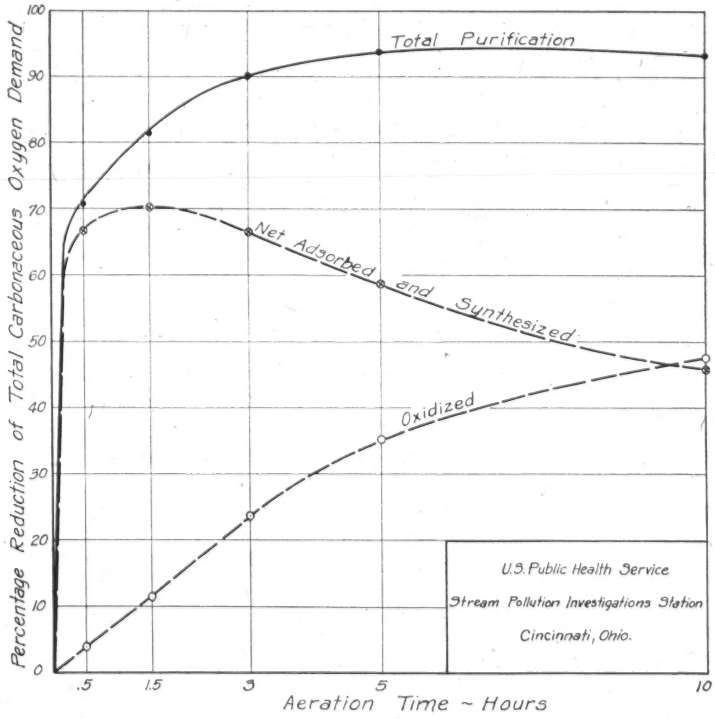

FIG. 10.—Reduction of total carbonaceous oxygen demand (L value) of settled sewage substrate aerated with activated sludge. Experiment 3. 2448 p.p.m. normal activated sludge. Initial substrate L value = 214 p.p.m.

The purification results as plotted in Fig. 9 for this experiment are quite different from those shown in Fig. 8. In this case the total purification is only about 40.7, 62.9, 66.5 and 89.2 per cent of the L value after 0.5, 1.5, 3 and 10 hours respectively, although in 24 hours a high value of 95 per cent was reached. The percentages of oxidation of the L value are also much lower than in experiment 1, being 1.0, 6.9, 12.3 and 31.5 after 0.5, 1.5, 3 and 10 hours. Consequently the net adsorbed and synthesized results attain a value of 56.0 per cent after 1.5 hours,

after which this value slowly increases reaching a maximum of about 60 per cent at about the 5th hour and then falls very slowly to about 58 per cent in 10 hours. After 24 hours of aeration about 50 per cent of the L value is still retained as adsorbed and synthesized materials. In this case the percentage oxidized has not reached 50.0 at the end of the

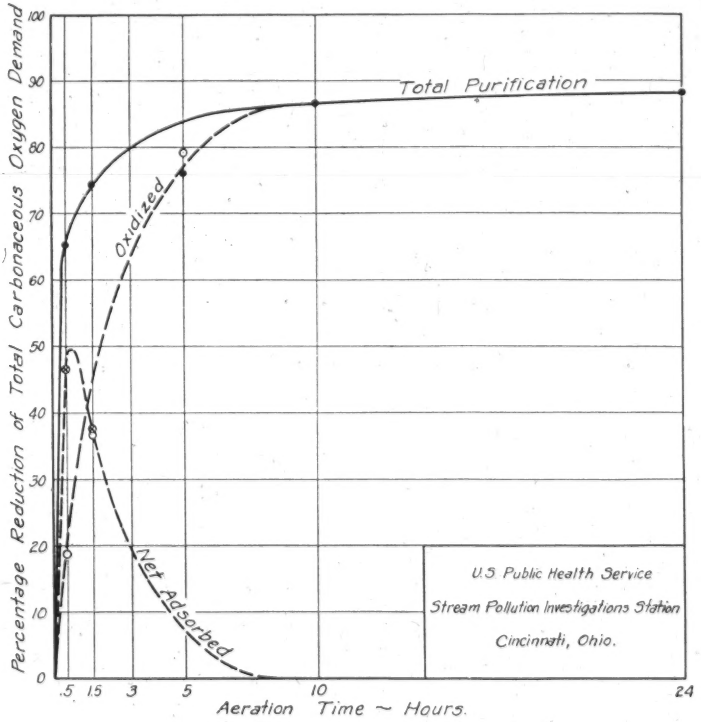

FIG. 11.—Reduction of total carbonaceous oxygen demand (L value) of settled sewage substrate aerated with activated sludge. Experiment 8. 3564 p.p.m. of an actively nitrifying activated sludge. Initial substrate L value = 135 p.p.m.

24 hour period. This may be interpreted as the result of an overdose of nutrient material for the quantity of sludge used in this experiment.

The results of experiment 3 are shown plotted in Fig. 10 and illustrate an intermediate condition between those of experiment 1 and 2. In this experiment the total purification is more rapid than in experiment 2 and very similar to that observed in experiment 1. The percentage oxidation results are considerably lower than those of experiment 1 and considerably higher than were observed in experiment

2. As a consequence, the net adsorbed and synthesized results reached a maximum of about 70 per cent at the end of the 1.5 hour period and then receded rapidly, falling below the percentage oxidized by the tenth hour. It seems apparent from the results presented in these three figures (8, 9 and 10) that the aeration time required for the percentage

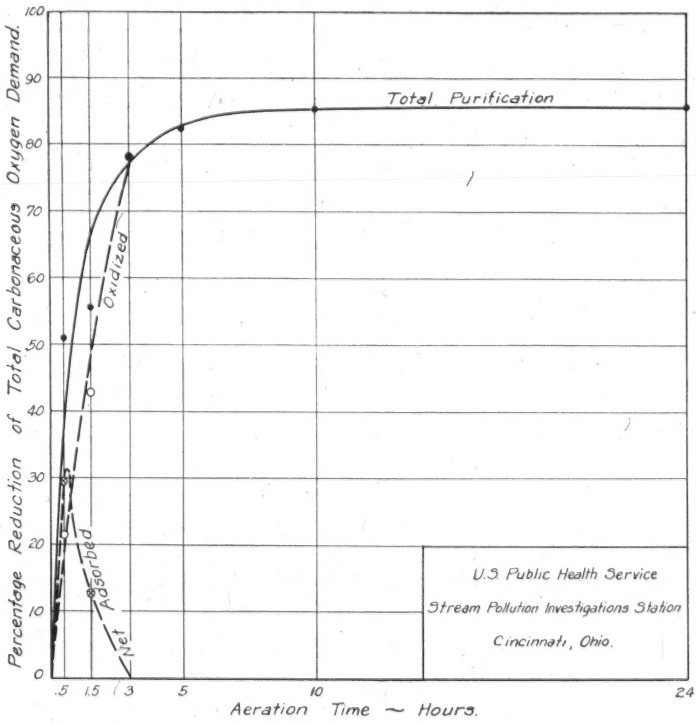

FIG. 12.—Reduction of total carbonaceous oxygen demand (L value) of clarified sewage aerated with activated sludge. Experiment 4. 2504 p.p.m. normal activated sludge. Initial substrate L value = 106 p.p.m.

oxidation to exceed the percentage net adsorbed and synthesized is an index of the adsorption-oxidation balance. A proper adsorption-oxidation balance is essential for the satisfactory operation of an activated sludge system.

At present the optimum proportion of oxidation to net adsorption and synthesis for any practical aeration time is unknown. It would seem from these experiments that Fig. 10 might illustrate a system with an approximately optimum adsorption-oxidation equilibrium.

The data obtained in two experiments in which the sludge actively nitrified the substrate during the 24-hour aeration period are plotted in Figs. 11 and 12. For reasons explained above no corrections for nitrification were made. It is possible that nitrification did not start until the third or fifth hour of aeration in which case the carbonaceous oxidation and adsorption relationships are about as indicated in the figures

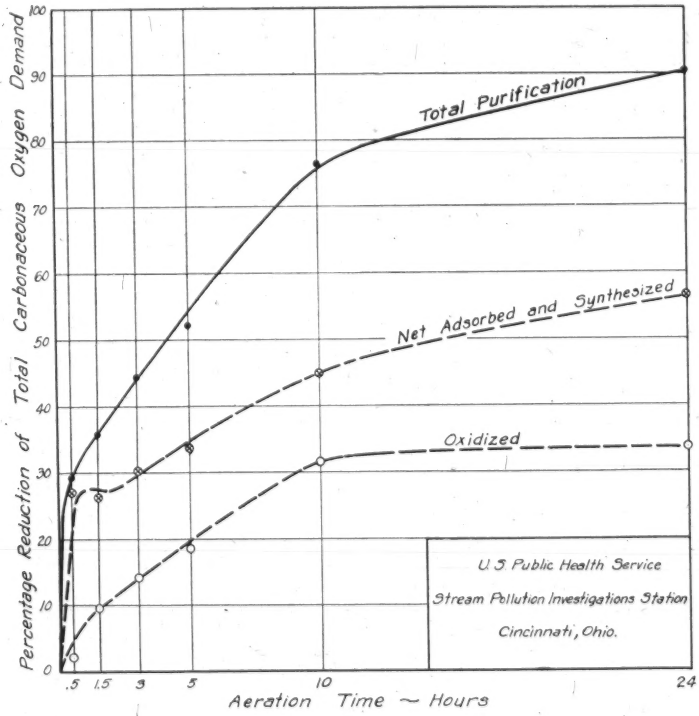

FIG. 13.—Reduction of total carbonaceous oxygen demand (L value) of synthetic sewage substrate aerated with activated sludge. Experiment 5. 2812 p.p.m. normal activated sludge. Initial substrate L value = 385 p.pm.

for the first three hours. It will be noted that the time at which the percentage of the substrate organic matter oxidized exceeds the percentage net adsorbed and synthesized in these experiments is much shorter than in experiments 1, 2 and 3 where nitrification had not been initiated. It seems reasonable to conclude that in experiments 4 and 8 most of the total purification of the substrate could be accounted for by oxidation by the end of the fifth hour of aeration and that the proportion of purification resulting from oxidation was higher than in the first

three experiments. It is also noted in experiments 4 and 8, with active nitrification, that the proportion of total purification resulting from adsorption and synthesis rapidly becomes negligible. Further studies on the course of total purification, carbonaceous oxidation, nitrification, and adsorption and synthesis of substrates aerated with nitrifying

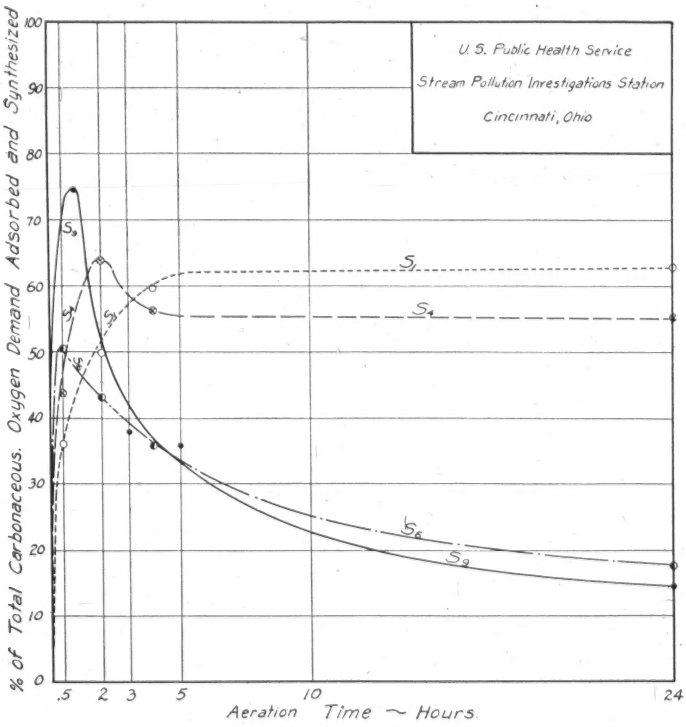

FIG. 14.—Types of curves for net adsorption of L value of substrates obtained during the development of an activated sludge. (Experiment 9.)

sludges are needed to interpret more intelligently the clarification phenomenon in such systems.

The data obtained in experiment 5 with a synthetic sewage substrate and normal activated sludge are plotted in Fig. 13. In this figure the curves are somewhat similar to those in Fig. 9 illustrating a case of overloading. But in this case the rate of total purification was much lower than in any of the experiments with domestic sewage. In fact, this rate is also very much lower than that obtained with similar substrates aerated with pure culture sludges.

The substrate oxidation rates with synthetic sewage in experiments 5 and 6 are similar to those with domestic sewage for the first few hours. Consequently, the failure of these sludges to remove the carbonaceous demand of colloidal and soluble material at a higher rate cannot be ascribed to a failure of bacterial oxidation. The proportion of the L value of the substrate to the quantity of sludge was even lower than this proportion in the pure culture sludge experiments. The results of experiments 5 and 6 in the normal activated sludge series indicate that such sludge does not have as great a capacity for removing organic matter from colloidal or true solution as does pure culture sludge. This may be interpreted as evidence indicating that the larger quantity of inert inorganic or mineral matter, which normal activated sludge always

TABLE XIV.—*Percentage of the Total Carbonaceous Oxygen Demand Reduction of the Substrate Actually Oxidized When Aerated with Non-Nitrifying Activated Sludge*

Experiment No.	Percentage Oxidized in Indicated Time in Hours					
	½	1½	3	5	10	24
1	8.15	23.8	37.9	61.9	72.9	79.2
2	2.46	11.0	18.5		35.3	47.8
3	5.52	13.8	26.2	37.4	51.0	
5	7.22	26.5	31.9	35.4	41.2	37.4
6	32.7	33.6	43.6	45.3	43.3	49.0
7	3.81	15.5		30.5	47.0	59.1
9–S4	1.13	15.7		22.7		26.0
9–S5	23.8	25.8		30.6		83.2
9–S6	18.1	31.6		39.2		79.0
Mean	11.4	21.9	31.6	37.9	48.4	57.6

Settled sewage used in Experiments 1, 2, 3, 7 and 9.
Synthetic sewage used in Experiments 5 and 6.

contains, reduces the capacity of the active bacterial surfaces for removing colloidal and soluble organic matter.

The percentages of the net adsorption and synthesis of the substrate L value obtained in a number of the tests made in experiment 9 are presented in Fig. 14. The four curves in this figures defining the rate of change in the percentage of the L value removed by adsorption and synthesis, illustrate the change in the form of the curves that takes place during the development of a good activated sludge. The first test (S1) was made after the aeration tank had been operated on the fill-and-draw principle for three days and 182 p.p.m. of sludge as suspended solids were present. The curve representing the net proportion of L value of the substrate adsorbed and synthesized for S1 has the same form as the total purification curve. The fourth test (S4) was made 28 days after aeration was started and 1188 p.p.m. of sludge as suspended solids were present. The net adsorption and synthesis curve for this test had changed form considerably from the first test and it will be noted that

it reached a maximum of about 63.8 per cent in 1.5 hours after which the percentage slowly dropped to 55.4 in 24 hours. In every test thereafter (S6, S9) a maximum point in the net percentage adsorbed and synthesized was reached at about the 0.5 to 1.5 hour aeration time and from this point on the values decreased. The maximum rate of reduction in the percentage net adsorbed and synthesized values was observed in the ninth test (S9) in which a small quantity of nitrate was found at the end of the experiment. The change in the form of these curves is ascribed to the increasing quantity of adsorbing surface and to the increasing capacity of the sludge to oxidize substrate during the early hours of aeration. Data on the development of the oxidizing capacity of the sludge have been presented in greater detail in an earlier paper.[9]

The proportions of substrate L value reductions produced by oxidation when the substrate is aerated with non-nitrifying sludge have been calculated and are shown in Table XIV. These data indicate again, as was the case with pure culture sludge, that oxidation is an important factor in B.O.D. removal with activated sludge. There is however, a considerable variation in the percentage of total purification accomplished by oxidation. After aeration for a half hour of settled sewage substrates with normal activated sludge from 2.45 to 23.7 per cent of the total observed purification was accomplished by oxidation. After 1.5 hours these values increased to 11.0 to 31.6 per cent and in 5.0 hours to 22.7 to 61.5 per cent. The data indicate that at the temperature of the experiment (20° C.) the percentage of total purification produced by oxidation varied with the condition of the sludge, with the dispersion and chemical composition of the substrate, and with the proportions of sludge and substrate in the mixture.

Discussion

These experiments have indicated the proportions of total removal of the carbonaceous biochemical oxygen demand of a substrate which may be credited to oxidation and to net adsorption and synthesis respectively, when various conditions obtain. Great differences in the ratio of the extent of oxidation to the net adsorption and synthesis occurred under conditions of underdosing and overdosing. Additional experiments, which are not described here, have shown the effect of prolonging these conditions on the activated sludge mechanism. It is certain that the quality and dosing rate of the substrate must be such as to promote an optimum oxidation, net adsorption and synthesis equilibrium for the continued success of the activated sludge process. If this is not done the efficiency of the process falls and eventually unexpected and formerly unexplainable failure results.

These experiments suggest that, although sludge reaeration is often resorted to as an activated sludge corrective measure, this is not always the proper procedure. A number of cases might be mentioned where sludge reaeration was harmful because the bacteria were not maintained in a state of activity for lack of food and the oxidation adsorption

equilibrium was upset. In general, it would appear that long aeration periods should be avoided when weak sewages are being treated. The data indicate that the ratio of sludge to sewage and the aeration period must be carefully adjusted to maintain the sludge in a state of optimum activity for maximum B.O.D. removal and economical operation. As long as sufficient air is used to keep all of the sludge suspended and dispersed throughout the liquor and to satisfy the oxygen requirements of the aeration mixture, the exact quantity is unimportant from the standpoint of sludge adsorption and oxidation efficiency. From the economic standpoint, therefore, the air should be adjusted to the minimum necessary to maintain the above conditions.

Summary and Conclusions

Two series of experiments have been performed, one with activated sludges developed by a pure culture of bacteria and one with normal activated sludge composed of grossly mixed bacterial species, including plankton. Some experiments with domestic sewage (as a substrate) and some with synthetic sewage, were carried out in each series. Each experiment was arranged so that estimations of the removal of the total carbonaceous oxygen demand (L value) of the substrate and also of the oxidation of the L value of the substrate were obtained simultaneously. The proportion of the L value of the substrate removed by oxidation and by net adsorption and synthesis and the total removal have been calculated for each experiment from the data obtained. The results for the proportions of purification of the substrate L value accomplished by these various mechanisms during the clarification stage of the activated sludge process have been plotted for a number of representative experiments. The following conclusions appear to be warranted by the results obtained.

1. There is a remarkable similarity between the purification accomplished by these mechanisms with both pure culture and normal activated sludges. This seems to justify the conclusion that the clarification mechanism of normal activated sludge is essentially the same as with the biologically simple, pure culture sludge.

2. The rate of removal of the L value (total carbonaceous B.O.D.) of the substrate is very high for the first half hour and this high rate may continue for an hour and a half or even three hours. From 80 to 95 per cent of the L value of a sewage substrate can be removed in five hours aeration with such sludges. The quantity and quality of the sludge influences the rate and extent of total purification accomplished in a given time.

3. The synthetic sewage used in these experiments contains no suspended matter and has undoubtedly a somewhat different chemical composition than sterile sewage. The fact that activated sludge reduced the L value of sterile sewage more rapidly than the L value of synthetic sewage indicates, therefore, that either the state of dispersion or the chemical composition or both may be factors which influence the

L value reduction of substrates. Nutrients in soluble form seemed to be more rapidly removed by pure culture sludge than by normal activated sludge.

4. The proportion of the L value reduction of the substrate that is actually oxidized varies from about 2.5 to 30 per cent in 30 minutes and these values are increased to 30 to 60 per cent after 5 hours aeration. These variations depend upon the quality and quantity of both sludge and substrate in the aeration mixture. From these results it must be concluded that biochemical oxidation is a factor of major importance to the success of the purification phenomenon.

5. The percentage of the L value removed from the substrate as a result of net adsorption and synthesis (all mechanisms other than oxidation) increases rapidly from the start for from 0.5 to 3.0 hours. During this period a maximum of about 50 to 70 per cent of the L value is removed by adsorption and synthesis. After the maximum point is reached the net percentage of the L value removed by adsorption and synthesis decreases. The rapidity of this decrease varies considerably in different systems and apparently depends to a great extent upon the oxidation mechanism.

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CARBON AND NITROGEN TRANSFORMATIONS IN THE PURIFICATION OF SEWAGE BY THE ACTIVATED SLUDGE PROCESS*

I. WITH MIXTURES OF SEWAGE AND ACTIVATED SLUDGE

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Heukelekian and Schulhoff (1) have reported that considerable clarification and purification of sewage was obtained when small amounts of clarifying bacteria isolated from activated sludge were inoculated into sterile sewage and incubated under quiescent condition. Some preliminary results were also reported by them on the carbon transformations obtained in the aeration of sewage with activated sludge or pure cultures. It was demonstrated that when activated sludge was used a greater part of the carbon lost from the liquid phase was recovered as sludge floc than when pure cultures were used. It was further stated that a more detailed study of this problem was desirable. The present investigation was therefore undertaken to answer the questions raised in the previous investigation:

1. What part, if any, of the original carbon and nitrogen in the sewage is transferred to the sludge?
2. How much of the carbon and nitrogen is oxidized from solution, suspension and sludge, with different periods of aeration?

The present study concerns itself mainly with the carbon and nitrogen transformations brought about in sewage by activated sludge. Subsequent papers will deal with similar changes brought about by sludges composed of pure culture sewage clarifying bacteria.

Method

Activated sludge was mixed in two concentrations with cotton-filtered, heat sterilized sewage to give mixtures with 1,850 p.p.m. and 464 p.p.m. total sludge solids. Six liters of each mixture were aerated in flasks fitted with CO_2-free air supply, as illustrated in Fig. 1. Any carbon dioxide which was evolved from the mixtures was trapped in standard barium hydroxide and measured. The alkali was renewed at the end of each sampling period. One-liter samples were taken from the mixtures of higher sludge concentration at 0, 1, 2, 3, 4 and 24 hours; and from the lower concentration at 0, 6, 9, 24 and 72 hours. Care was exercised to obtain as representative samples as possible for analysis. One hour of settling was provided for the sampled mixture after which the sludge and settled liquor were measured and separated. Corrections were made for the liquid that could not be separated from the

* Journal Series Paper, New Jersey Agricultural Experiment Station, New Brunswick, New Jersey, Dept. Water and Sewage Research.

sludge by plain sedimentation. The sludge was analyzed for total solids, organic solids, ash, inorganic carbon, organic carbon, and total nitrogen. The settled liquor was analyzed for turbidity, B.O.D., ammonia nitrogen, total nitrogen (Kjeldahl), nitrate nitrogen, organic nitrogen, inorganic carbon and organic carbon. Following the distribution for the required analyses, the remainder of the settled liquor was filtered through Seitz filter pads to remove suspended matter. The fraction thus obtained, representing the Seitz filtrate, was analyzed for ammonia nitrogen, total nitrogen, nitrate nitrogen, organic nitrogen, inorganic carbon and organic carbon. Turbidity, ammonia nitrogen and B.O.D. analyses were made as soon as the necessary fractions were obtained, while samples for all other analyses were preserved in stoppered bottles. Sulfuric acid, sodium hydroxide and mercuric chloride

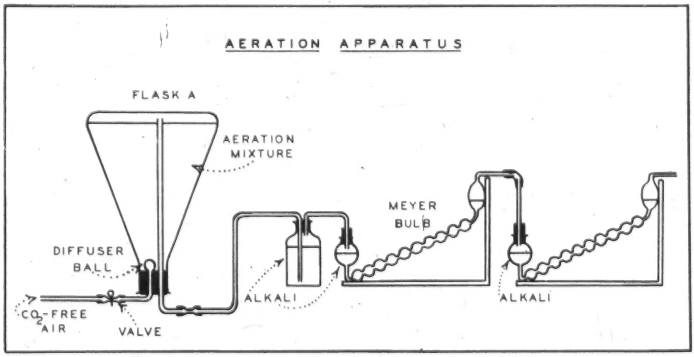

FIG. 1.

were the preserving agents for the total nitrogen, nitrate nitrogen and carbon samples respectively. Following the end of aeration with both series, analyses of preserved samples were made at leisure.

CARBON DETERMINATION

Preliminary to the experimental work with activated sludge and sewage the carbon determination method was studied. The moist combustion method of Mills (2) (3) modified by the titration technic of Mohlman and Edwards (4) was simplified by replacing fused glass connections with rubber stoppers and detachable glass parts (see Fig. 2). Consistent low blanks (inorganic carbon 0.16 mg., organic carbon 1.24 mg.) over an eight months period, during which more than 150 carbon determinations were made, demonstrated that the use of rubber stoppers failed to impair the efficiency of the apparatus. A ratio of 1.5:1 of sulfuric acid to water was found to be just as efficient as a ratio of 3:1 or 2:1 in the determination of organic carbon in sewages and activated sludges. The titration technic of Mohlman and Edwards was

modified whenever large amounts of carbon were present in the sample under analysis. The modification consisted of the separation, after settling, of the barium carbonate precipitate and relatively clear supernatant liquid. The supernatant was titrated rapidly almost to the phenolphthalein end point, mixed with the barium carbonate precipitate and then titrated drop by drop to the end point. In this manner, a reduction of time necessary for the drop-by-drop back-titration of barium hydroxide with hydrochloric acid was made, also minimizing the error from the absorption of carbon dioxide from the air by the exposed alkali during a prolonged titration period of large amounts of alkali. The air supplying the apparatus was regulated at point 5 (Fig. 2) at a slow rate such that all of the evolved carbon dioxide was trapped in the first two absorption flasks (K_1, K_2) leaving the third carbonate-

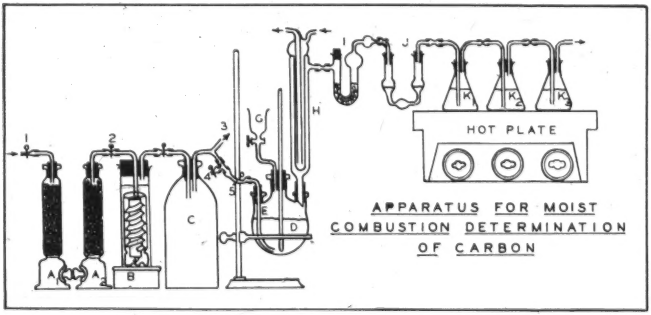

FIG. 2.

free. The use of soda lime tubes at the end of the absorption train to guard against back-diffusion of the atmosphere as recommended by Mills (2) was found unnecessary.

Judging from the sharpness of the phenolphthalein end point, the theoretical sensitivity of the method is 0.03–0.06 milligrams carbon. Average sensitivity of the apparatus used in the analysis of pure inorganic and organic carbon compounds was found to be $\pm$ 0.28 milligrams of carbon.

Inorganic carbon, consisting of carbon dioxide in solution plus inorganic carbonates, was determined by clearing the apparatus of carbon dioxide, introducing the sample, acidifying with several drops of concentrated sulfuric acid and aspirating the boiling sample for one hour. The carbon dioxide evolved was trapped in hot standard barium hydroxide and measured indirectly by back-titration with hydrochloric acid. Organic carbon was determined on the same sample by adding 1.0 c.c. of silver sulfate, 10 c.c. of chromium trioxide and 1.5 c.c. of concentrated sulfuric acid per 1.0 c.c. of sample. The contents of the combustion flask were heated to 150° C. and aspirated for two hours at this temperature.

Results

Purification.—Purification of the sewage, as indicated by the removal of B.O.D. and turbidity (Fig. 3), was rapid in the sewage-sludge mixture of 1,850 p.p.m. solids; one hour's aeration reduced the B.O.D.

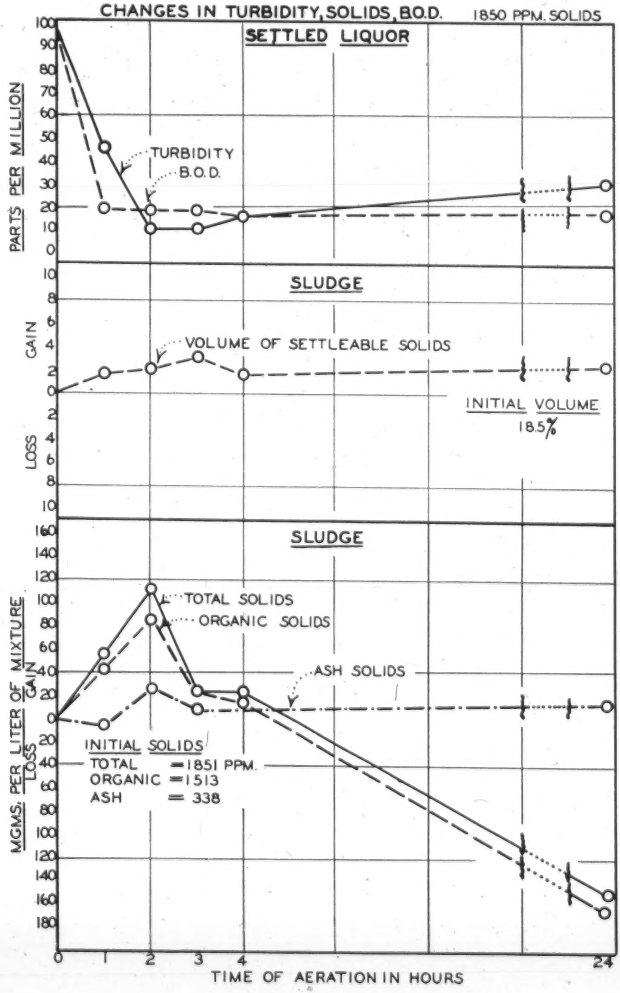

Fig. 3.

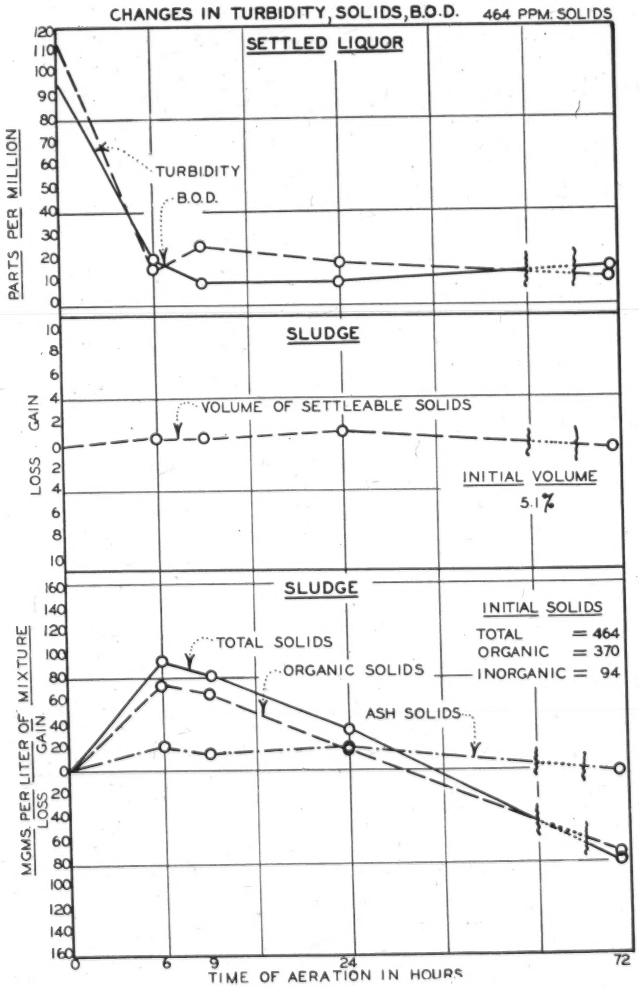

FIG. 4.

from 96 to 19 p.p.m. and turbidity from 98 to 45 p.p.m. At the end of four hours of aeration turbidity was 15 p.p.m. and B.O.D. the same, while continued aeration up to 24 hours raised the turbidity to 30 p.p.m. and B.O.D. to only 16 p.p.m.

Reduction of B.O.D. and turbidity of the settled liquor from the sewage-sludge mixture of low solids content (Fig. 4) was slower, requiring six hours of aeration to reduce the B.O.D. from 118 to 16 p.p.m. and turbidity from 98 to 20 p.p.m. Continued aeration up to 72 hours increased the turbidity of the settled liquor but not the B.O.D.

It was essential to determine the time period necessary for purification in the two mixtures of high and low sludge concentrations. This period was taken to represent the length of time required to produce the maximum purification, beyond which continued aeration failed to produce appreciable further purification. According to B.O.D. and turbidity values, the purification period would be placed at 1.0 to 2.0 hours for the high solids mixture and 6 to 9 hours for the low solids mixture. If the organic carbon values in the settled liquor were also included as criteria, the purification periods would be extended to 4 and 9 hours respectively for the high and low solids mixtures (Tables I and II). While considerable amounts of nitrates were produced during the purification periods in each mixture (Tables III and IV), and although the quantity of nitrates increased progressively with aeration beyond these periods, complete nitrification was not considered an essential desideratum in the activated sludge process. It was felt, therefore, that for the conditions of the experiment, 4 and 9 hours for the high and low solids mixtures, respectively, represented safe estimates for the periods of purification. The volume of sludge in both mixtures showed slight increases during the aeration period, indicated in Figs. 3 and 4. However, the amount of total and organic solids of the sludge of both mixtures showed a considerable increase during the early periods of aeration, followed by a steady decline with longer periods of aeration. The amount of ash in the sludge of both mixtures followed the increase of total solids.

Carbon Transformations.—The progressive changes which occurred in the carbon contents of the sludge, settled liquor and Seitz filtrate, and the carbon dioxide produced in both mixtures, are presented in Tables I and II and Figs. 5 and 6. It was observed that the carbon in the entire mixture of high solids (sludge plus settled liquor plus carbon dioxide evolved) increased from 914 to 941.6 mg. in 1.0 hour of aeration and to 964.1 in 2.0 hours, thereafter decreasing to the original level. There was no possible explanation for this except on the basis of sampling error. Since the carbon values of the entire system were derived from the summation of the separately determined inorganic and organic carbon values of the settled liquor and sludge, an error in sampling one component may have affected the totals obtained. Since the sampling error was greatest in the sludge component, and since there was little inorganic carbon in the sludge, the fluctuations in the totals obtained in the carbon balance can be attributed to the organic carbon found in the sludge. Assuming the initial value of the carbon of the whole mixture to be correct, the percentage variation from the initial value fluctuated from -1.4 to $+5.5$ per cent, with an average variation of $+1.5$ per

TABLE I.—*Carbon Changes in an Aerating Mixture of Activated Sludge and Sewage Containing 1850 p.p.m. Sludge Solids*

	Inorganic Carbon, p.p.m.	Organic Carbon, p.p.m.	CO_2 Produced as Carbon		Total Carbon, p.p.m.	Per Cent Experimental Error
			At Each Interval, p.p.m.	Per Hour, p.p.m.		
0 hours						
Settled liquor	26.8	82.7	0	—	109.5	
Solution (Seitz)	10.9	35.3				
Suspension	15.9	47.4				
Sludge	1.6	802.9			804.5	
Total carbon					914.0	—
1 hour						
Settled liquor	21.2	45.3	8.7	8.7	75.2	
Solution (Seitz)	13.3	33.3				
Suspension	7.9	12.0				
Sludge	6.0	860.4			866.4	
Total carbon					941.6	+3.0
2 hours						
Settled liquor	16.5	37.3	20.6	20.6	74.4	
Solution (Seitz)	9.4	20.0				
Suspension	7.1	17.3				
Sludge	5.6	884.1			889.7	
Total carbon					964.1	+5.5
3 hours						
Settled liquor	14.1	23.4	14.5	14.5	52.0	
Solution (Seitz)	3.9	12.7				
Suspension	10.2	10.7				
Sludge	6.6	842.8			849.4	
Total carbon					901.4	−1.4
4 hours						
Settled liquor	9.3	32.6	17.0	17.0	58.9	
Solution (Seitz)	7.6	24.0				
Suspension	1.7	8.6				
Sludge	8.6	850.4			859.0	
Total carbon					917.9	+0.4
24 hours						
Settled liquor	3.7	40.6	134.0	6.8	178.3	
Solution (Seitz)	2.1	32.0				
Suspension	1.6	8.6				
Sludge	7.6	730.0			737.6	
Total carbon					915.9	+0.2
Average experimental error						+1.5

TABLE II.—*Carbon Changes in an Aerating Mixture of Activated Sludge and Sewage Containing 464 p.p.m. Sludge Solids*

	Inorganic Carbon, p.p.m.	Organic Carbon, p.p.m.	CO_2 Produced as Carbon		Total Carbon, p.p.m.	Per Cent Experimental Error
			At Each Interval, p.p.m.	Per Hour, p.p.m.		
0 hours						
Settled liquor	8.5	82.0	0	—	90.5	
Solution (Seitz)	8.4	35.0				
Suspension	0.1	47.0				
Sludge	0.7	192.5			193.2	
Total carbon					283.7	—
6 hours						
Settled liquor	8.4	52.0	26.0	4.3	86.4	
Solution (Seitz)	8.4	46.0				
Suspension	0	6.0				
Sludge	3.1	229.3			232.4	
Total carbon					318.8	+12.3
9 hours						
Settled liquor	9.3	40.6	17.1	5.7	67.0	
Solution (Seitz)	9.0	17.3				
Suspension	0.3	23.3				
Sludge	1.4	232.0			233.4	
Total carbon					300.4	+5.9
24 hours						
Settled liquor	9.3	50.6	39.2	2.6	99.1	
Solution (Seitz)	8.9	16.7				
Suspension	0.4	33.9				
Sludge	1.4	220.5			221.9	
Total carbon					321.0	+13.1
72 hours						
Settled liquor	4.5	42.0	55.6	1.15	102.1	
Solution (Seitz)	4.2	21.3				
Suspension	0.3	20.7				
Sludge	0.3	158.4			158.7	
Total carbon					260.8	−8.1
Average experimental error						+5.8

cent. While the percentage increase of carbon in the sludge during the first hour was 6.8 per cent, the percentage increase of carbon in the entire mixture for this period was only 3 per cent. For the second

TABLE III.—*Nitrogen Changes in an Aerating Mixture of Activated Sludge and Sewage Containing 1850 p.p.m. Sludge Solids*

	Organic Nitrogen, p.p.m.	Nitrate Nitrogen, p.p.m.	Ammonia Nitrogen, p.p.m.	Total Nitrogen, p.p.m.	Per Cent Experimental Error
0 hours					
Settled liquor	6.8	0.2	20.0	27.0	
Solution (Seitz)	3.9	0.2	20.0		
Suspension	2.9	0	0		
Sludge				140.5	
Total—N				167.5	—
1 hour					
Settled liquor	8.2	3.2	12.0	23.4	
Solution (Seitz)	4.3	3.2	12.0		
Suspension	3.9	0	0		
Sludge				144.9	
Total—N				168.3	+0.5
2 hours					
Settled liquor	6.7	6.4	9.0	22.1	
Solution (Seitz)	1.5	6.4	9.0		
Suspension	5.2	0	0		
Sludge				151.9	
Total—N				174.0	+3.9
3 hours					
Settled liquor	5.7	10.7	2.6	19.0	
Solution (Seitz)	2.7	10.7	2.3		
Suspension	3.0	0	0.3		
Sludge				148.0	
Total—N				167.0	−0.3
4 hours					
Settled liquor	6.9	16.0	1.0	23.9	
Solution (Seitz)	2.7	16.0	1.0		
Suspension	4.2	0	0		
Sludge				149.9	
Total—N				173.8	+3.8
24 hours					
Settled liquor	8.4	32.0	0.6	41.0	
Solution (Seitz)	3.6	32.0	0.6		
Suspension	4.8	0	0		
Sludge				132.8	
Total—N				173.8	−3.8
Average experimental error					+2.3

TABLE IV.—*Nitrogen Changes in an Aerating Mixture of Activated Sludge and Sewage Containing 464 p.p.m. Sludge Solids*

	Organic Nitrogen, p.p.m.	Nitrate Nitrogen, p.p.m.	Ammonia Nitrogen, p.p.m.	Total Nitrogen, p.p.m.	Per Cent Experimental Error
0 hours					
Settled liquor	3.8	0.5	24.0	28.3	
Solution (Seitz)	1.0	0.5	24.0		
Suspension	2.8	0	0		
Sludge				33.9	
Total—N				62.2	—
6 hours					
Settled liquor	6.5	6.4	10.0	22.9	
Solution (Seitz)	2.9	6.4	10.0		
Suspension	3.6	0	0		
Sludge				43.7	
Total—N				66.6	+7.1
9 hours					
Settled liquor	1.6	10.7	7.0	19.3	
Solution (Seitz)	1.7	10.7	7.0		
Suspension	−0.1	0	0		
Sludge				44.5	
Total—N				63.8	+2.6
24 hours					
Settled liquor	2.8	18.0	0.5	21.3	
Solution (Seitz)	2.0	18.0	0.5		
Suspension	0.8	0	0		
Sludge				41.1	
Total—N				62.4	+0.3
72 hours					
Settled liquor	2.5	30.0	0.6	33.1	
Solution (Seitz)	2.4	30.0	0.6		
Suspension	0.1	0	0		
Sludge				28.1	
Total—N				61.2	−1.6
Average experimental error					+2.1

hour period the corresponding values were 9.3 per cent as against 5.5 per cent. The increases obtained in the organic carbon of the sludge are therefore of greater magnitude than the experimental error, and represent actual increases in the sludge due either to adsorption of carbonaceous materials from the settled liquor or the formation of new protoplasmic material from the food introduced. The actual increase

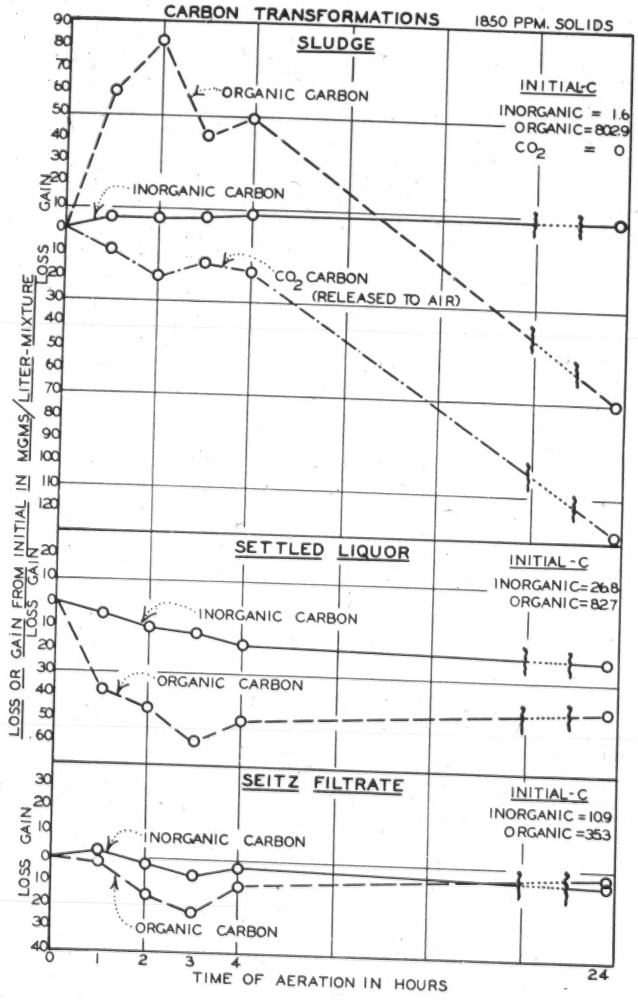

FIG. 5.

in the amount of total and organic solids in the sludge confirmed the increase in the organic carbon of the sludge. The magnitude of the experimental error in the carbon balance with the low solids mixture was of the same order as that with the high solids mixture but the

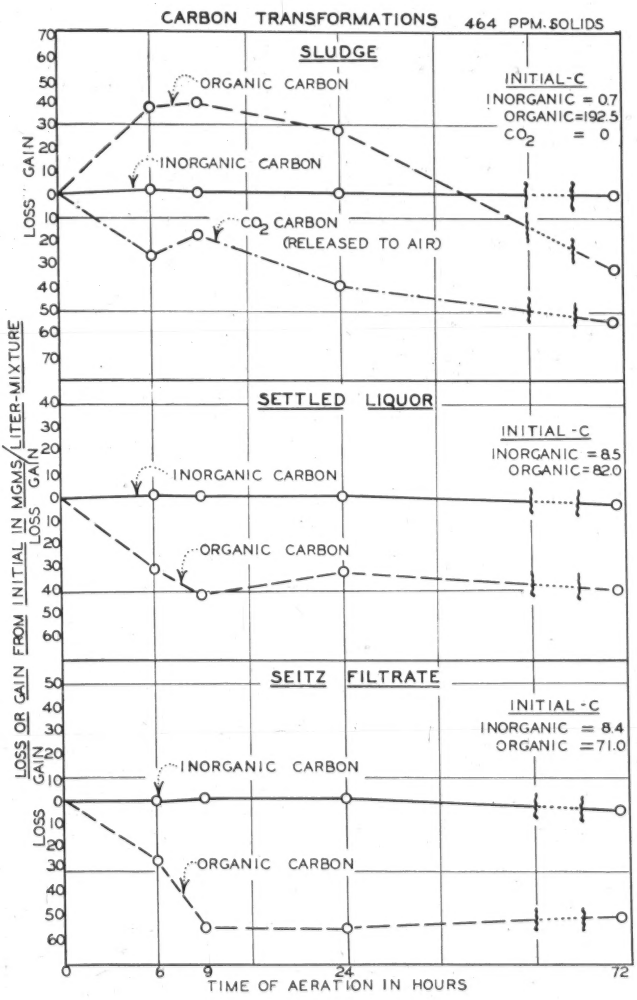

FIG. 6.

percentage experimental error was greater because of the relatively low carbon values.

Definite identical trends occurred in the carbon contents of the various fractions in both mixtures. Carbon in the sludge floc was al-

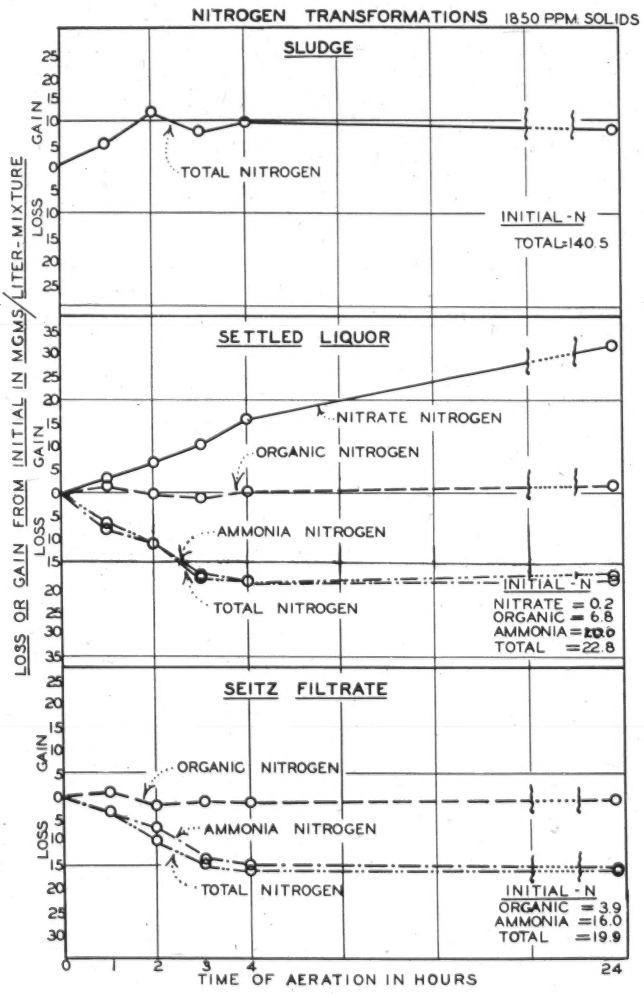

FIG. 7.

most entirely organic in nature. Carbon changes in the sludge floc were confined exclusively to the organic fraction, which increased in the initial period of aeration, accompanied simultaneously by a fall of inorganic and organic carbon content of the settled liquor. Aeration

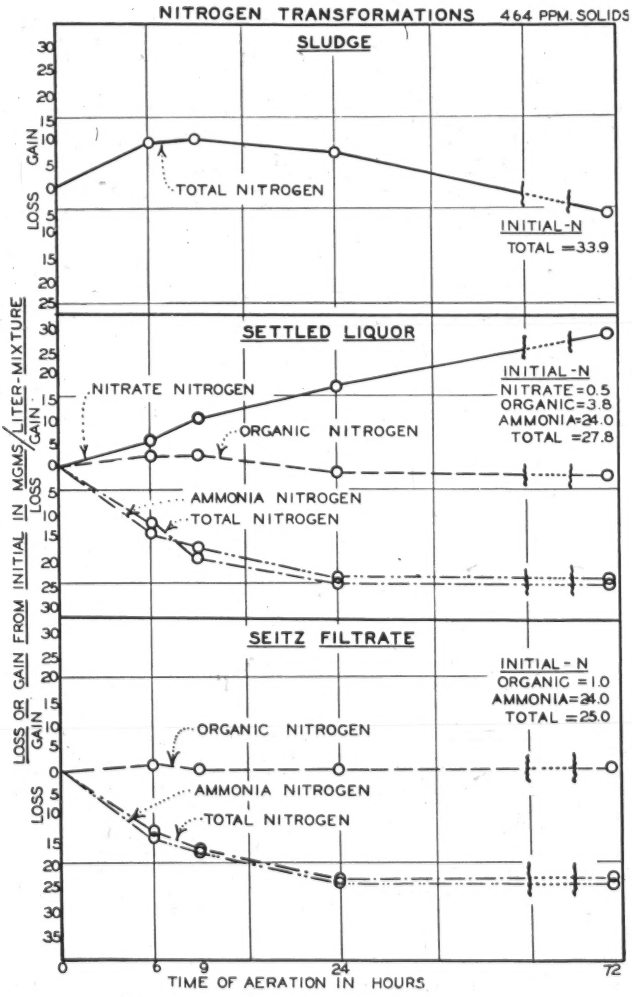

Fig. 8.

beyond the period of purification of both mixtures, at which time available carbonaceous materials in the settled liquor were depleted, produced a steady oxidation of the carbon contained in the sludge floc itself. In Fig. 5, the curve of carbon dioxide released beyond the fourth

hour of aeration parallels closely the decrease of organic carbon of the sludge over the same period. The same was true of the sludge of the low solids mixture (Fig. 6) but to a lesser extent. Another factor contributing to the loss of organic carbon from the sludge floc with over-aeration, was deflocculation of the sludge solids, resulting in a rise in both organic carbon content and turbidity of the settled liquor.

The hourly rate of carbon dioxide produced by the sewage-sludge mixture of high solids (Table I) reached a maximum of 20.6 milligrams of carbon in the second hour of aeration, followed by a decrease with progressive aeration. Throughout the 24-hour aeration period, 194.8 milligrams of carbon as carbon dioxide was liberated to give an overall rate of 4.38 mg. carbon/hour/1,000 p.p.m. sludge solids. Maximum hourly rate of carbon dioxide production from the sewage-sludge mixture of low solids (Table II) occurred at the ninth hour of aeration and was followed by a lowering of the rate with progressive aeration. In 72 hours of aeration 137.9 mg. carbon as carbon dioxide was liberated, to yield an overall rate of 4.13 mg. carbon/hour/1,000 p.p.m. sludge solids.

Nitrogen Transformations.—Changes occurring in the nitrogen content of the different fractions of the sewage-sludge mixtures are given in Tables III and IV and Figs. 7 and 8. The nitrogen balance of the mixture of high solids shown in Table III varied between — 0.3 to + 3.9 per cent with an average of + 2.3 per cent, while the total nitrogen of the low solids mixture varied between — 1.6 to + 7.1 per cent with an average of + 2.1 per cent difference from the initial value.

Total nitrogen of the sludge in both mixtures rose slightly in the initial period of aeration. During the first 4 hours of aeration in the mixture of high solids, the ammonia nitrogen lost was nearly balanced by the nitrate nitrogen recovered. From the fourth to the twenty-fourth hour of aeration, ammonia nitrogen of the settled liquor decreased only 0.4 p.p.m., organic nitrogen increased 1.5 p.p.m. while nitrate nitrogen in the settled liquor increased 16.0 p.p.m. Coincidentally with the net increase in the settled liquor of 17.1 p.p.m. nitrogen, the total nitrogen of the sludge floc fell 17.1 p.p.m.

After 9 hours of aeration the ammonia nitrogen in the settled liquor of the low solids mixture decreased 17.0 p.p.m., and organic nitrogen decreased 2.2 p.p.m. An increase of 10.2 p.p.m. nitrate nitrogen produced, therefore, a net loss of 9.0 p.p.m. nitrogen from the settled liquor, which loss was offset by a 10.6 p.p.m. gain of nitrogen in the sludge floc. From the ninth to the seventy-second hour of aeration, ammonia nitrogen of the settled liquor decreased 6.4 p.p.m. while there were gains of 0.9 p.p.m. organic nitrogen and 19.3 p.p.m. nitrate nitrogen, to produce a net gain of 13.8 p.p.m. nitrogen in the settled liquor. This gain was more than offset by a loss of 16.4 p.p.m. nitrogen from the sludge floc. Aside from the rise in total nitrogen in the sludge, nitrate nitrogen increased progressively at the expense of ammonia nitrogen. While organic nitrogen in the settled liquor of the low solids mixture

decreased with aeration, the settled liquor of the high solids mixture showed little change in this constituent.

Discussion

In the first hour of aeration of the high solids sewage-sludge mixture, there was a 35.4 p.p.m. decrease of suspended organic carbon in the settled liquor, while organic carbon in solution decreased only 2 p.p.m. Organic carbon of the sludge increased meanwhile by 57.5 p.p.m. As has been pointed out above, although the increase of sludge carbon cannot be doubted, the actual magnitude of the increase was affected by sampling error. The increase of carbon in the sludge should be equal to the loss of carbon, both from suspension and solution in the settled liquor, minus the carbon dioxide produced. This value amounts to 28.7 p.p.m. Assuming that organic matter contains 57 per cent carbon, there would be a loss of 50 p.p.m. of organic matter by the settled liquor and a gain by the sludge of the same amount. Actually organic solids in the sludge increased 42 p.p.m. during the first hour. It appears, therefore, that the amount of carbon transferred to the sludge from solution and suspension (28.7 p.p.m.) represents more accurately the the increase in sludge carbon.

There are two possible ways by which organic carbonaceaus materials can be transferred from the liquid to the sludge. The first is by adsorption by the floc, and the second by bacterial assimilation. Although both these factors are at work, it would seem that, during the first hour, adsorption was the predominant one. Remembering that materials in suspension have higher molecular weights than those in solution, according to Traube's rule quoted by Thomas (5), adsorption of homologous series from aqueous solutions increases with increasing molecular weight of the members. Heukelekian and Ingols (6) have found this rule to be generally true in the removal of nitrogenous materials of different molecular weights by activated sludge. Since the loss of carbon from the liquid phase was primarily from suspension rather than from solution during the first hour, it appears reasonable to attribute the mechanism of this removal to adsorption. Furthermore since only a small fraction of the carbon lost from solution and suspension during the first hour was recovered as carbon dioxide, it would seem that this material was removed from the liquid to the sludge faster than it was oxidized.

During the second hour of aeration the carbon relationship was completely changed. There was no further loss of organic carbon in suspension, but instead of 13.3 p.p.m. loss of organic carbon from solution. Rate of carbon dioxide production during this period was much higher and the increase of organic carbon in the sludge was not so great as that during the first hour. During the third and fourth hours, loss of organic carbon from solution and suspension continued, the rate of carbon dioxide production dropped and sludge formation, as indicated by the carbon and organic matter content of the sludge,

was arrested, with a reversal of sludge formation probably occurring shortly after this period. The course of events can be summarized as, first, rapid adsorption of suspended organic carbon from the settled liquor, resulting in rapid removal of turbidity and B.O.D., with considerable building up of sludge; second, oxidation of the soluble organic carbon accompanied by some building up of sludge and considerable increase in carbon dioxide production; and third, over-aeration beyond the purification period, resulting in the oxidation of sludge, decrease of organic carbon of the sludge with an increase of organic carbon in solution, a slow rate of carbon dioxide production, and increase of turbidity.

The removal of organic carbon from the settled liquor after 3 hours of aeration was not complete, as the lowest organic carbon value of the settled liquor was 23.4 p.p.m. a decrease of only 72 per cent of the intitial value. Assuming 57 per cent carbon in organic matter this would represent a minimum of 41 p.p.m. of organic matter in the effluent. With about 46 per cent of this material in suspension there would be 19 p.p.m. organic matter suspended in the effluent. This is a high value for activated sludge effluent, and should be ascribed to the fact that determination of suspended matter by Seitz filtration gives much higher values than ordinary Gooch filtration. Since the B.O.D. reduction was 81 per cent, it may be concluded that residual organic carbon in the liquor was highly resistant to oxidation and probably represents products of bacterial metabolism from the sludge which find their way into the liquor. The nature of such carbonaceous materials can only be speculated upon, but humic materials might be mentioned as a possibility. The brown color imparted to the settled liquor as a result of over-aeration has frequently been ascribed to accumulation of humic acids.

A similar analysis of the data with the mixture of low suspended solids content leads to the same conclusions as above, except in time relationship. Since the first determination was made after 6 hours of aeration, changes during the first few hours are unknown. The major part of the organic carbon in suspension was removed during this period, while the organic carbon in solution increased. Organic carbon of the sludge increased 36.8 p.p.m. equivalent to an increase of organic matter of 65 p.p.m. (organic matter, 57 per cent carbon). The actual increase of organic solids in the sludge was 75 p.p.m. From the sixth to the ninth hour of aeration organic carbon in solution declined considerably while that in suspension increased. Neither sludge carbon nor organic solids of the sludge increased during this period. While aeration up to 24 and 72 hours did not change materially the organic carbon in solution or suspension in the settled liquor, there was a decline in the sludge of organic solids and carbon. The rate of carbon dioxide production in the first 6 hours of aeration was low, while a rapid removal of suspended carbonaceous material and building up of sludge was taking place. The rate of carbon dioxide production was highest between the sixth and ninth hours of aeration while organic carbon in

solution was declining rapidly. Thereafter the rate of carbon dioxide production decreased materially. Maximum reduction of organic carbon in the settled liquor, found at the ninth hour of aeration of the low solids mixture, was a little over 50 per cent. B.O.D. reduction at this time was 78 per cent.

The difficulty in the proper interpretation of the results may be realized if we bear in mind that any and all of the following changes may take place simultaneously: (1) adsorption by the sludge of organic carbon in suspension in the settled liquor; this action was observed to be pronounced during the initial stages of aeration (2) oxidation of the adsorbed carbon; this action was pronounced during the secondary stage of aeration, (3) slow oxidation of the organic matter of the sludge itself; this action was predominant with overaeration after the purification period, (4) oxidation of carbon in solution; this action was noted during the secondary stage of aeration (5) assimilation of part of the carbon to form new bacterial cells in the sludge floc, concurrent with oxidation of carbon in solution and carbon in the material absorbed on the floc, (6) increase of carbon in solution as a result of waste products of bacterial metabolism going into the surrounding medium; this was found to occur during the period of overaeration.

It is evident that there are two mechanisms which tend to increase the amount of sludge: (1) The initial rapid adsorption by the sludge of material from suspension in the settled liquor, and (2) the oxidation of both the adsorbed material and material in solution with the resulting increase in the amount of microbiol cell mass. To apportion the proper value to these two factors is difficult. The initial increase in the sludge due to adsorption of material from suspension represented only a temporary increase, since this material was subject to microbial digestion, oxidation and assimilation exerted by the sludge micro-organisms. As aeration progressed, therefore, the quantity of sludge formed due to adsorption decreased while that due to microbial assimilation increased. That even the increase of sludge quantity due to microbial assimilation was not permanent was evidenced by the results presented with periods of over-aeration, during which there occurred a profound decrease of organic carbon and organic matter of the sludge. Microbial growths and the more resistant materials in the sludge were destroyed during this period.

The transformation of organic nitrogen was quite different from that of organic carbon. In the first place, the amount of organic nitrogen in the settled liquor represented only a small fraction of the total nitrogen. Secondly, the results failed to show any rapid removal of organic nitrogen from the liquid phase similar to the carbon results. In fact, the organic nitrogen in suspension increased during the first 2 hours of aeration while that in solution decreased.

In the mixture of high solids concentration, during the first hour of aeration ammonia nitrogen in the settled liquor decreased 8 p.p.m. while nitrate nitrogen increased 3 p.p.m. During this same period sludge nitrogen increased 4.4 p.p.m. Since Ingols (7) demonstrated

that activated sludge did not adsorb ammonia nitrogen, the increase of sludge nitrogen was attributed to microbial assimilation. Similarly, at the end of the second hour 11 p.p.m. decrease of ammonia nitrogen in the settled liquor was obtained while 6.2 p.p.m. nitrate nitrogen was recovered, the remainder of 4.8 p.p.m. being assimilated. By actual determination sludge nitrogen rose 11.4 p.p.m. This discrepancy can probably be explained on the basis of sampling error of the sludge rather than to adsorption of nitrogen since there is no loss from the settled liquor of organic nitrogen in suspension. Nitrogen fixation as a possible explanation for the increase of sludge nitrogen is rather remote. The third and fourth hour balances showed likewise that the majority of the ammonia nitrogen lost from the settled liquor was recovered as nitrate nitrogen and the remainder of the nitrogen not so recovered was accounted for in part by an increase in sludge nitrogen. From the fourth to twenty-fourth hour of aeration however, the amount of nitrate nitrogen recovered was greater by 15.6 p.p.m. than the ammonia nitrogen lost. Organic nitrogen increased 1.5 p.p.m. to produce a net increase in the settled liquor of 17.1 p.p.m. This nitrogen was derived from the decomposition of the nitrogen fraction of the sludge which underwent a loss of 17.1 p.p.m. during this period. In other words, prolonged aeration of the sludge caused the breakdown of the organic nitrogen to ammonia nitrogen which was nitrified as liberated.

The nitrogen changes in the mixture with low solids content showed similar tendencies. The organic nitrogen in the settled liquor did not decrease during the first 6 hours of aeration but actually increased somewhat. Between the sixth and ninth hours organic nitrogen in the settled liquor decreased appreciably due probably to proteolytic activity of bacteria present. Of the 6.5 p.p.m. organic nitrogen present in the settled liquor after 6 hours of aeration, only 1.6 p.p.m. was left after 9 hours, all of it being present in the Seitz filtrate. There is again a greater loss of ammonia nitrogen from the settled liquor than can be accounted for by nitrate formation, and this loss may be directly attributable to assimilation of ammonia nitrogen by the sludge floc. This situation persisted up to 24 hours of aeration; thereafter the recovery of nitrate nitrogen was higher than the original ammonia nitrogen, the balance being made up of the nitrogen lost from the sludge.

From the foregoing discussion of carbon and nitrogen changes, it is apparent that the difference between the low and high solids mixtures is in the time necessary to bring about these changes, rather than in type and character of the changes.

In order to estimate the percentage of the organic carbon removed from sewage by activated sludge which was recovered as carbon dioxide, it was necessary to determine the amount of carbon dioxide produced from the sewage component. The assumption was made that beyond the purification period of both mixtures *i.e.*, 4 and 9 hours, respectively, the carbon dioxide released represented a basal rate produced by the sludge alone and that the residual sewage material either in the sludge floc or in the liquor contributed very little carbon dioxide to the amount

released during this secondary period. The calculations made on this basis are presented in Table V. The percentage of organic carbon removed from the sewage which was recovered as carbon dioxide was 67.9 and 71.5 per cent, respectively, for high and low solids mixtures. The release of carbon as carbon dioxide from the mixture of high solids after the purification period was 6.7 mgm. carbon/hour/1,850 p.p.m. sludge solids or 3.62 mgm. carbon/hour/1,000 p.p.m. sludge solids, while that for the low solids mixture was 1.5 mgm. carbon/hour/464 p.p.m. sludge solids or 3.24 mgm. carbon/hour/1,000 p.p.m. sludge solids. That the basal rates of carbon dioxide release calculated from mixtures of such widely different concentrations should agree so well indicated that the initial contention was substantially correct, *i.e.*, that beyond the purification period the carbonaceous materials present in the sewage contributed very little to the carbon dioxide released.

TABLE V.—*Percentage of Organic Carbon Removed From Sewage by Activated Sludge Which was Liberated as Carbon Dioxide*

	Solids in Mixture	
	1850 p.p.m.	464 p.p.m.
1. Period in hours necessary for purification	4.0	9.0
2. CO_2 produced during purification periods, mgm.C.	60.8	43.1
3. Period of aeration after purification, hours	20.0	63.0
4. CO_2 produced during period after purification, mgm.C.	134.0	94.8
5. CO_2 produced per hour during period after purification, mgm.C.	6.7	1.5
6. CO_2 contributed by the sludge itself during the purification period, mgm.C.	26.8	13.5
7. Difference between 2 and 6 representing CO_2 produced from sewage component, mgm.C.	34.0	29.6
8. Organic carbon removed from sewage during purification period, mgm.C.	50.1	41.4
9. Percentage of carbon removed from sewage recovered as CO_2 during purification period	67.9	71.5

The portion of carbon transferred from the sewage to the sludge which is not liberated as carbon dioxide can be accounted for, first, in the carbon assimilated in the microbial cells and second, in the unassimilated and undecomposed residual organic matter in the sludge floc. According to the above calculations, about two-thirds of the organic carbon removed from the sewage is given off as carbon dioxide and one-third remains in the sludge either as unassimilated material or in the bacterial protoplasm. This statement supports the contention of Heukelekian and Ingols (8) that carbon dioxide production from mixtures might be a more reliable way of determining the load on an aeration tank than B.O.D. because carbon dioxide measurements are made under conditions more comparable to the aeration tanks than B.O.D. measurements. The figures presented above on percentage organic carbon of the settled liquor lost as carbon dioxide are, at first glance, at great variance with those of Wilson and McLachlan (9) who stated that "only about 10 per cent of the transformation products of the carbon origi-

nally in the sewage appears as carbon dioxide in the effluent air . . . and that the transference of carbon from sewage to the sludge is the major purifying effect." This value and statement will be discussed later.

One objection which can be raised to our method of calculating percentages of carbon dioxide release may be that the assumption made is not valid, *i.e.*, that after the purification period, carbon dioxide liberated by the sewage-sludge mixture did not represent the true basal rate of carbon dioxide liberated by the sludge itself; and that the release of carbon dioxide from sewage solids present either in the sludge floc, or in the settled liquor fraction, may have occurred beyond the period of purification and raised the basal rate of carbon dioxide production from the sludge. Even if such were the case, and the true basal rate of carbon dioxide release from the sludge were lower than the value we obtained, this circumstance would tend to raise the percentage of organic carbon lost as carbon dioxide rather than lower it. For example, if in the mixture of high solids, the release of carbon dioxide in 4 hours from the sludge floc, calculated from the basal rate, was 24.0 mgm. carbon instead of 26.8 mgm., the carbon dioxide liberated from the sewage solids would be 36.8 mgm. With a lowering of the organic carbon of the settled liquor of 50.1 mgm. carbon, the percentage of organic carbon of the settled liquor lost as carbon dioxide would be $36.8 \div 50.1$ or 73.5 per cent instead of the 67.9 per cent calculated.

The apparently wide discrepancy between our values and those of Wilson and McLachlan was found to exist not so much in differences in experimental data as in their interpretation. These investigators calculated the percentages of carbon dioxide released on the total carbon input of both settled sewage and activated sludge, rather than on organic carbon lost from the sewage upon aeration, which loss is a truer measure of the biological activity of activated sludge than the total carbon input.

Changes in percentages of carbon and nitrogen and C/N ratio of the sludge floc are presented in Tables VI and VII. Upon aeration with sewage, the sludges of both mixtures showed an increase in percentages of carbon and nitrogen, coincident with the removal of carbonaceous and nitrogenous materials from the settled liquor fraction. When both mixtures were over-aerated, percentages of carbon and nitrogen decreased to their original levels, connoting the dissipation of most of the effects of the sewage solids taken up by the sludge floc. No significant changes in the C/N ratio of the sludge floc occurred during the aeration periods. It has been contended that the mechanism of uptake by the sludge of organic carbon in suspension was one of adsorption; that the adsorbed material which is subsequently oxidized together with dissolved organic carbon contributes to microbial growth in the sludge floc, necessitating the assimilation by the sludge of ammonia nitrogen from the surrounding medium. The chief reason why the C/N ratio of the sludge changed very little upon aeration with sewage was because

growth of the sludge floc produced microbial material similar to the original sludge. Adsorption of suspended organic materials in the initial period of aeration did not alter the C/N ratio because of the great organic carbon content of the sludge and the relatively small amount of material adsorbed. While the percentage of both carbon and nitrogen increased with aeration during the purification period, the C/N ratio changed very slightly. Part of the microbial growth underwent a breaking down with over-aeration, liberated carbon dioxide, and released inorganic and organic carbon simultaneously with a diffusion of organic and ammonia nitrogen into the liquid. Ammonia nitrogen

TABLE VI.—*Carbon-Nitrogen Ratio of Sludge Floc in an Aerating Mixture of Activated Sludge and Sewage Containing 1850 p.p.m. Sludge Solids*

Hour	Total Solids, p.p.m.	Total Carbon, p.p.m.	Total Nitrogen, p.p.m.	Per Cent C	Per Cent N	C/N
0	1850	804.5	140.5	43.4	7.6	5.7 : 1
2	1964	889.7	151.9	45.3	7.7	5.9 : 1
3	1874	849.4	148.0	45.3	7.9	5.7 : 1
4	1875	859.0	149.9	45.8	8.0	5.7 : 1
24	1698	737.6	132.8	43.4	7.8	5.6 : 1

TABLE VII.—*Carbon-Nitrogen Ratio of Sludge Floc in an Aerating Mixture of Activated Sludge and Sewage Containing 464 p.p.m. Sludge Solids*

Hour	Total Solids, p.p.m.	Total Solids, p.p.m.	Total Nitrogen, p.p.m.	Per Cent C	Per Cent N	C/N
0	464	193.2	33.9	41.6	7.3	5.7 : 1
6	559	232.4	43.7	41.6	7.8	5.3 : 1
9	547	233.4	44.5	42.8	8.1	5.3 : 1
24	498	221.9	41.1	44.6	8.2	5.4 : 1
72	382	158.7	28.1	41.6	7.3	5.7 : 1

subsequently was nitrified. The loss of carbon and nitrogen kept pace with each other to cause very little change in the C/N ratio.

In order to determine whether the sum of carbonaceous and proteinaceous materials present was equal to the organic matter present in the activated sludge, an attempt was made to calculate the amounts of these materials present, from the analysis of carbon and nitrogen in the sludge, on the following two assumptions: (1) The carbon content of carbonaceous materials present in activated sludge is 57 per cent. This value was arrived at by averaging the carbon content of several carbonaceous materials such as fats, hemicelluloses, celluloses and lignins, the relative amounts of which in activated sludges have been determined in a study on the organic constituents of activated sludge. These studies will be published soon in another paper, (2) Proteins

contain 15 per cent nitrogen and 52 per cent carbon according to Mathews (10). A sample calculation follows:

		Mgms.
Organic carbon (by analysis)	=	803
Organic nitrogen (by analysis)	=	140.5
Proteins (140.5×6.66)	=	937
Total carbon in proteins ($937 \times .52$)	=	487
Organic carbon not in proteins ($803 - 487$)	=	316
Carbonaceous compounds ($316 \div .57$)	=	554
Proteins plus carbonaceous compounds	=	1,491
Organic matter in sludge (analysis)	=	1,513

By using the above assumptions and method of calculation the proteins and carbonaceous materials in the sludge at various periods of aeration were calculated for both mixtures. The results are presented in Tables VIII and IX together with the amount of organic solids ob-

TABLE VIII.—*Theoretical Composition of the Organic Solids of the Activated Sludge Floc in an Aerating Mixture of Activated Sludge and Sewage Containing 1850 p.p.m. Sludge Solids*

Hour of Aeration	Protein (calc.)* p.p.m.	Carbonaceous (calc.)* p.p.m.	Total Solids (analysis) p.p.m.	Ash Solids (analysis) p.p.m.	Organic Solids (analysis) p.p.m.	Organic Solids (calc.) p.p.m.	Per Cent Proteins†	Difference, p.p.m.
0	937	554	1850	338	1512	1491	62	−21
2	1013	626	1964	365	1599	1639	63	+40
3	987	579	1874	346	1528	1566	64	+38
4	999	579	1875	348	1527	1578	65	+51
24	885	474	1698	353	1345	1359	66	+14

* Calculated.

† Protein (calculated) divided by organic solids (by analysis).

TABLE IX.—*Theoretical Composition of the Organic Solids of the Activated Sludge Floc in an Aerating Mixture of Activated Sludge and Sewage Containing 464 p.p.m. Sludge Solids*

Hour of Aeration	Protein (calc.)* p.p.m.	Carbonaceous (calc.) p.p.m.	Total Solids (analysis) p.p.m.	Ash Solids (analysis) p.p.m.	Organic Solids (analysis) p.p.m.	Organic Solids (calc.) p.p.m.	Per Cent Proteins†	Difference, p.p.m.
0	226	132	464	94	370	358	61	−12
6	291	137	559	114	445	428	65	−17
9	297	136	547	109	438	433	68	− 5
24	274	137	498	112	386	411	71	+25
72	187	107	382	89	293	294	64	+ 1

* Calculated.

† Protein (calculated) divided by organic solids (by analysis).

tained by analysis. It will be observed that there is a very close agreement between the calculated values of organic matter on the basis of the carbonaceous and proteinaceous materials and the organic matter ob-

tained by analysis. In the high solids mixture at the start of aeration the calculated value for organic matter in the sludge was lower than the observed value. After two hours of aeration the reverse was true, for the calculated value was higher than the observed value and with further aeration the differences became smaller. It would appear, then, that although the assumptions made are valid for the composition of activated sludge, they do not apply strictly to the character of the sewage solids which exerted an influence on the results during the intermediate periods of aeration.

According to these results, nearly 62 per cent of the organic matter in activated sludge is in the form of proteins. The origin of the sludge nitrogen is not the organic nitrogen of the sewage which itself is low and changes little, but the ammonia nitrogen. It would seem that the major portion of the protein in the sludge is composed of microbial protoplasm synthesized from the ammonia nitrogen and carbonaceous materials present in the sewage.

Summary and Conclusions

Two different concentrations of sludge-sewage mixtures were aerated for periods of time to bring about purification and for periods beyond that to cause definite over-aerated conditions. Determinations of organic and inorganic carbon were made on the settled liquor, Seitz filtrate and the sludge portions. Organic nitrogen was determined on the settled liquor and Seitz filtrate and the sludge portions. Ammonia and nitrate nitrogen, turbidity and B.O.D. of the settled liquor were also determined.

From the results obtained the following conclusions were drawn:

(1) The carbon of the sludge increased at the expense of suspended organic carbon in the liquor with short periods of aeration (one hour with 1,850 p.p.m. solids concentration). This was attributed to adsorption of carbonaceous materials by the sludge.

(2) The removal of organic carbon in suspension was followed by the removal of organic carbon in a finer state of dispersion (Seitz filtrate). This phenomenon was attributed to the biological assimilation of these materials by the sludge floc, since it was accompanied by a high rate of carbon dioxide production.

(3) The rapid removal of organic carbon from suspension and the slower removal by oxidation of organic matter in a finer state of dispersion resulted in an increase in the amount of sludge, first by physical accretion and second, by microbial assimilation.

(4) The effect of aeration beyond the purification period was to increase in the liquor (*a*) the organic carbon in suspension as a result of deflocculation of the sludge and (*b*) organic carbon in a finer state of dispersion as a result of liberation of end products of bacterial metabolism such as humic acids.

(5) Organic nitrogenous compounds in the liquor, representing only a small fraction of the total nitrogen present, are not adsorbed by the

sludge, since the nitrogen failed to decrease during early periods of aeration.

(6) The nitrogen transformations in the activated sludge process were (*a*) the quantitative conversion of ammonia nitrogen to nitrate nitrogen (*b*) the bacterial assimilation of some of the ammonia nitrogen and (*c*) the liberation into the liquor of a part of the sludge nitrogen as ammonia with periods of over-aeration and sludge break-down and the conversion of this ammonia to nitrate nitrogen.

(7) Calculations showed that 65 to 75 per cent of the organic carbon of sewage removed by activated sludge during the purification was recovered as carbon dioxide.

(8) The carbon: nitrogen ratio of the activated sludge was approximately 5.7/1. Although the percentages of carbon and nitrogen of the sludge increased upon aeration with sewage, the carbon: nitrogen ratio of the sludge changed very little, due to the fact that growth of the sludge floc produced microbial material similar to the original sludge itself.

(9) The sum of the carbonaceous and nitrogenous materials obtained from calculations using organic carbon and nitrogen content of the sludge and certain well accepted percentages for carbon and nitrogen in analogous materials, added up to the total organic solids obtained by analysis. Proteins were present in the activated sludge in excess of carbonaceous materials. Average protein content of the activated sludge was 65 per cent and carbonaceous compounds 35 per cent.

(10) Variations in the quantities of sludge in the activated sludge process did not change the nature of the transformations described above, differences between the high and low solids concentration being limited only to the time required to bring about the transformations.

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Plant Operation

TALLMANS ISLAND SEWAGE TREATMENT WORKS*

By Henry Liebman and E. J. Fort

Designing Engineer and Project Engineer

The World's Fair slogan "The Dawn of the New Day" can be used very properly in describing the status of sewage disposal in the City of New York. After years of complete disregard of this problem, the conscience of the city has been awakened and we are now embarked on a program of purification of the surrounding waters.

The Tallmans Island Plant, the third of the major projects to be constructed under the comprehensive plan for sewage treatment embodying thirty-two proposed plants, was pushed forward on account of the World's Fair. This plant, with the Bowery Bay Plant now under construction, will effectively abate the nuisance of pollution in Flushing Bay, which adjoins the site of the Fair.

The area served by the Works extends from the city line at Little Neck westerly to Flushing Bay and from the East River southerly to the boundary line between the northerly and the southerly slopes of the island. It includes the former villages of Flushing, College Point, Whitestone, Bayside, Douglaston, and a part of Little Neck. The area included within these boundaries is 17,000 acres or 26½ square miles. This area is not densely settled and is used almost exclusively for residential purposes. The present population is estimated at 150,000 and the ultimate at 580,000 by 1970. The present plant is designed for a population of 290,000 and a flow of 40 M.G.D. which is one-half the ultimate. During the World's Fair approximately 10 to 15 M.G.D. additional flow will be treated at the Tallmans Island Plant.

The site, which is known as "Tallmans Island," is a point of land which juts into the East River between the former villages of Whitestone and College Point and contains about 35 acres (Fig. 1). The whole of this area was purchased by the city to provide for the extension of the works when the increase in the volume of sewage makes it necessary. The present works occupy only one-half of the area available, the balance is being landscaped with shrubs, lawns and trees. Extensive landscaping is being provided in order that the presence of the sewage plant should in no way depreciate the value of the surrounding property.

A high degree of treatment is required for the waters in the vicinity of the works. For various reasons, it was decided to use the activated sludge process at this particular plant. Subsequent to the decision to

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build this type of plant, the waters were designated as Class "A" water by the Interstate Sanitation Commission.

Class "A" waters are defined as those which are expected to be used primarily for recreational purposes, shellfish culture or the development of fish life. All floating solids and at least 60 per cent of suspended solids shall have been removed. Organisms of the *B. coli* group in the sewage effluent shall not exceed one per cubic centimeter. Dissolved oxygen in the waters shall not be less than 50 per cent of saturation in any week of the year.

Sewage enters the works through three intercepting sewers: the main sewer, 7 ft. by 7 ft. in cross-section, which diverts sewage from a

FIG. 1.—General view taken November 15, 1938, looking north from pump and blower house—Whitestone Bridge in distance.

main outlet sewer at 32nd Avenue and Linden Street; a 36-in. sewer carrying sewage from College Point and the immediate vicinity; and a 12-in. sewer which carries a small amount of sewage which could not be intercepted otherwise than by pumping. The main sewer is connected directly to the inlet structure of the grit chamber. The 36-inch sewer is connected to a low-level wet well and then pumped into the inlet of the grit chamber, since this sewer reaches the plant at a much lower elevation than the large sewer.

The treatment given the sewage consists chiefly in the removal of screenings and grit, primary settling, aeration in the presence of 25 per cent return sludge, final settling and dilution in the East River. Sludge digestion is provided together with gas utilization for power and heating purposes and sludge disposal at sea.

The main components of the plant are as follows:

Grit and Screen Chamber
Pump and Blower House
Primary Settling Tanks
Aeration Tanks
Final Settling Tanks
Sludge Thickening Tanks
Sludge Digestion Tanks
Supernatant Settling Tank
Sludge Storage Tanks
Dock and Outfall Sewer.

The Grit and Screen Chamber

The grit chamber is of the highly mechanized type intended to remove the larger solids and grit from the sewage with a minimum amount of land labor and without causing nuisances. The chamber is entirely enclosed and provided with positive ventilation. All grit removed from the sewage is washed and conveyed in closed pipe lines to storage and all screenings are shredded and returned to the sewage.

The chamber contains four channels whose capacity is sufficient for the ultimate storm flow of 160 M.G.D. Three of the channels are completely equipped and one will be equipped in the future when the flow increases. At the entrance of each channel is a hydraulically operated sluice gate arranged for both hand and automatic control. In case the level in the grit chamber rises above a pre-determined elevation, the gates will shut. Each channel contains a hand-raked trash rack made of wrought iron, tapered bars and cast-iron support sills. The bars are set at 3 in. centers, the T-angles and supports are sunk below the invert and no cross bars are used. In this way, the racks can be raked easily and there are no cross bars for stringy material or rags to wrap around. Behind the trash racks are enclosed mechanically cleaned bar screens that have clear openings of one inch. Each mechanically cleaned screen has four rakes which travel at a speed of 15 ft. per minute. The frequency and the speed of raking insures a continually cleaned screen and limits the amount of material and screenings delivered to the grinders at one time.

The channels are approximately 60 ft. in length, 12 ft. in width and have a water depth of 6 ft. at mean flow. The velocity through the channels is controlled by means of proportional weirs to about 1 ft. per second. At this velocity most of the grit is deposited. The grit is then scraped to a sump at the head of the channel by means of conveyor type scrapers. A bucket elevator removes the grit from the sump and discharges it into a combined screw and dewatering conveyor type washer. Here, the grit is washed, using clarified effluent as the washing water. In this way, it is expected that a cleaner grit will result over that which would be obtained by washing in the sewage. The screenings discharged from the mechanically cleaned screen are probably one of the

most offensive products we have to deal with in sewage treatment. The simplest way of disposing of this material is by grinding and returning directly to the sewage. The screenings from the mechanically operated screens are discharged directly into the screenings grinders of the swing hammermill type which are driven by direct connected 30 H.P. 1,800 r.p.m. motors and have a capacity of about 1,400 lb. per hour. The washed grit is discharged from the washers into pneumatic ejectors and blown into a storage tank in the grit storage building.

The storage tank is a circular, welded steel tank with a conical bottom and has a capacity of about 4,000 cu. ft. and is elevated for gravity loading of trucks. Poke holes are provided at four points to break up any arching, and a clamshell type discharge gate allows free discharge. It is enclosed in a small building shown in Fig. 2, which also contains a four car garage. This arrangement provides protection from the

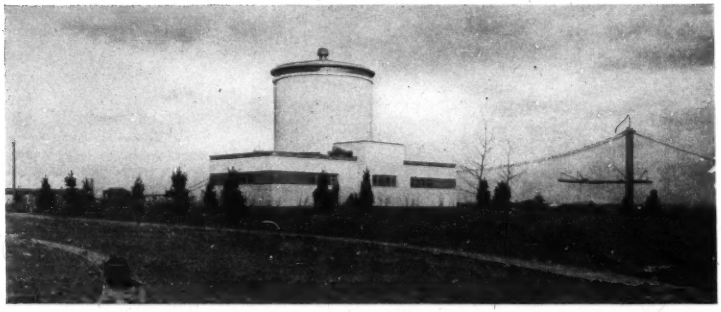

FIG. 2.—Grit storage building and garage.

weather for the cars and grit trucks stored here and the maintenance of a temperature in the tank which prevents freezing of the wet grit.

Since the quantities of screenings and grit vary widely, the equipment was specified for peak conditions. The screens are capable of handling 60 cu. ft. of screenings per hour and the grit equipment loads of 60 cu. ft. of grit per M.G.D. based on a peak flow of 40 M.G.D. per channel.

PUMP AND BLOWER HOUSE

The pump and blower house shown in Fig. 3, is a modern structure approximately 170 ft. long, 140 ft. wide and 50 ft. high. The pumps and blowers, all the auxiliary equipment, cranes, electrical control, meters, indicators, and so forth, in addition to the offices, laboratories, machine shops, store rooms and filter rooms are located in this building and its wings.

The sewage from the grit chamber passes directly to the wet well in the pump and blower house. The wet well extends the entire length of the building, approximately 170 ft. Four pumps, with provision for a

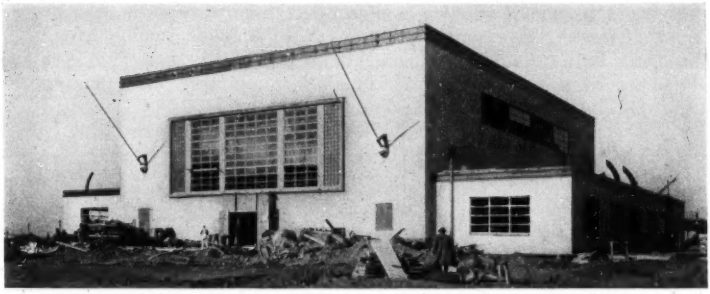

FIG. 3.—Pump and blower house.

fifth, draw suction from the wet well and discharge into a common main which goes to the primary tanks. There are two pumps of 35 M.G. capacity and two of 15 M.G. capacity, designed for 39 ft. head. The pumps are vertical centrifugal pumps driven by means of gas engines, shown in Fig. 4, two of which are rated at 150 B.H.P. and two of which

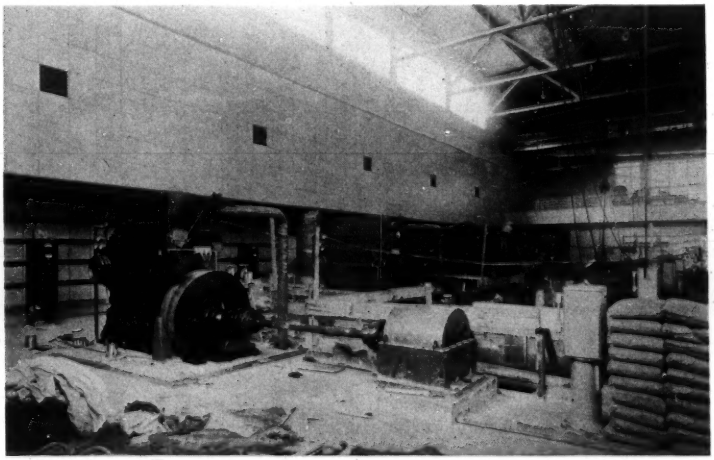

FIG. 4.—Gas engines and right angle gears for driving pumps (note finished wall).

are rated at 350 B.H.P. Since the engines are horizontal and the pumps are vertical, a right-angle gear is used to transfer the power from the engines to the pumps. The right-angle gears are connected to the gas engines by a floating section of shafting fitted with flexible couplings at each end. The capacity of the pumps can be varied over a wide range from 50 to 110 per cent by means of speed control of the engines. This

feature is invaluable in sewage plant operation owing to the wide variations in flow. The larger pumps are 36 in. and the smaller are 20 in. in size. It is intended in the future to replace the two smaller units with two 36 in. units and to add one additional 36 in. unit, making the final installation five-35 M.G. pumps.

The sewage coming from the low level of the College Point Interceptor is raised by means of one 14 in. pump with a capacity of 5,800 gallons per minute and two 12 in. pumps with a capacity of 2,500 gallons per minute, into the influent end of the grit chamber. These pumps are

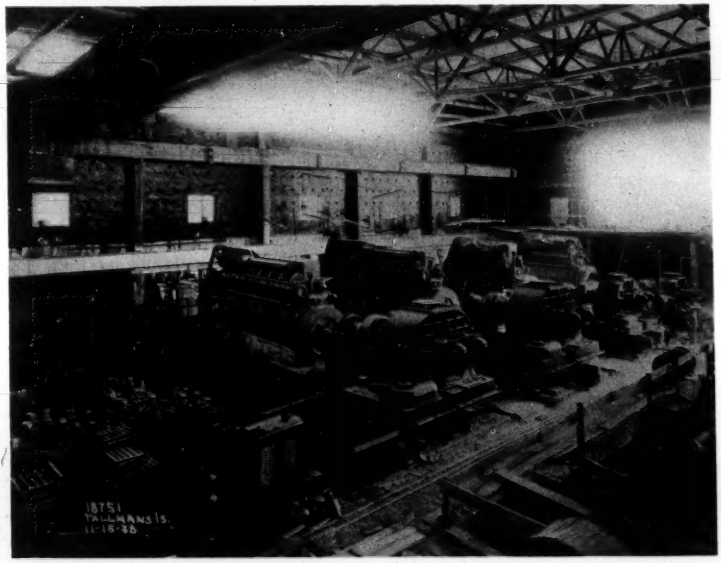

FIG. 5.—Gas engine driven blowers.

driven by electric motors operated by current purchased from the local utility.

On the east side of the building four blowers, shown in Fig. 5, have been installed for supplying compressed air for aeration of the sewage. Two of these blowers have a capacity of 10,000 c.f.m. and two have a capacity of 20,000 c.f.m. operating at 7½ lbs. discharge pressure. They are of the positive displacement type. The larger units operate at 300 r.p.m. and the smaller at 360 r.p.m. These units are also gas-engine driven and by means of speed control of the engines, their output can be varied from 33 to 110 per cent of rated capacity. The larger units are driven by two 800 H.P. engines, the smaller units by two 450 H.P. engines. The blowers are connected to the engines through an all-

metal flexible coupling. The air supplied will be doubly filtered by an automatic oil filter followed by a cellulose dry filter.

The type of gas engine selected was based on our experience at the Coney Island Plant. The engines are of the slow speed, vertical, multi-cylinder 4-cycle, heavy duty type. They are totally enclosed, presenting a clean, sleek appearance. Each engine was tested in the shop at its rated brake horsepower to demonstrate its ability to meet the requirements. The exhaust gas can be passed through a waste heat exchanger or by-passed around it and then through a silencer to the atmosphere. The air supplied to the engines is filtered. The heated jacket water is used for heating the building and digestion tanks. In the summer, effluent water will be used to cool the jacket water. A heat exchanger is installed in the jacket water circuit for this purpose. The engine foundations are separate massive blocks of concrete, resting on a slab which is isolated from the building to prevent any transmission of vibration.

In the basement of the pump and blower house are located all the miscellaneous auxiliaries including heat exchangers, fuel and oil pumps and tanks, oil purifiers, starting air compressors and receivers and a complete gas-fired heating plant. The pump and blower house is of sufficient size to serve the ultimate plant.

Primary Settling Tanks

Sewage is delivered through the force main, which contains a venturi meter for measuring the total flow, to the inlet channel of the primary sedimentation tanks.

There are three tanks, each 124 ft. long, 50 ft. wide and 13½ ft. side wall depth. The design detention period at average flow of 40 M.G.D. is one hour. The sludge is removed by straight-line collectors, three in each tank and three cross collectors to sumps at the inlet end of the tank. The scraper blades of the main collectors on their return travel act as skimmers and push the scum to the outlet end of the tanks. At this point, an auxiliary scraper mechanism, which is activated by the main collector, pushes the scum into a trough from which it flows to a sump manhole located alongside the preliminary pumping station. Here, the scum will be allowed to separate on top. The water will be subcanted from the manhole and returned to the wet well; the scum will be pumped into the digestion tanks. The sludge will be removed from the sludge sumps by means of three 4 in. plunger pumps located in the sludge pumping station, one pump being connected to each tank. A cross connection is provided also so that any pump can draw from any tank in case of a pump failure. Experience has shown that better control of pumping is afforded in this way by having a pump for each tank. The pumps are motor-driven by two speed motors directly connected to two speed gears, which are connected directly to the crank shaft of the pump. In this way, variation in deliveries of 130, 80, 65, and 40 gallons per minute can be obtained.

The sewage enters the tanks through eighteen 24 in. gates, which are provided with baffles. The outlet of the tanks is over weirs which extend along the entire width of 150 ft. into a channel which serves as a by-pass channel when the remaining units are by-passed or when the works are operated to provide only sedimentation. By means of four venturi meters, connecting this channel to the aeration tanks, settled sewage can be introduced at various points in the aeration tanks.

Aeration Tanks

The aeration tank layout was based on a design contemplating the use of the reaeration principle. When operating on a simple aeration cycle with 40 M.G.D. and 25 per cent return sludge, the aeration period is 3.3 hours. On the reaeration cycle, the sludge may be reactivated for widely varying periods as may be required.

There are two aeration tanks 373 ft. long with four passes per tank. Each pass is 22 ft. 3 in. wide. The water depth is 15 feet. Space is available for a third tank in the area assigned to the first half of the plant. The return sludge channel is at the north end of the tanks and in normal operation the entire sewage flow may be admitted through this channel. The channel is aerated and sewage and sludge will be thoroughly and evenly mixed before entering the tanks.

The four 30-in. venturi meters which connect the effluent channel of the primary tanks with the south end of the aeration tanks make it possible to admit sewage in any proportions desired at both ends of the tanks and at various points along the line of flow through the tanks.

The tanks are of the spiral-flow type with curved walls so that the transverse velocity will be high and the period of contact of air and sewage may be somewhat increased.

Air under pressure of about 7 lb. per sq. in. at the compressor will be furnished through a 36-in. force main extending to the north end. This main is carried to and through a pipe gallery at the north end of the aeration tanks and decreases in size as the lateral mains and the branches carrying air to the air lift pumps and the aerated channels are connected to it. The lateral mains are laid in the tops of the tank walls. They vary in diameter from 16 to 8 inches. Air is admitted to the sewage through a double line of porous plates laid on the bottom and at one side of each channel.

The plate holders are of reinforced concrete and carry Aloxite brand carborundum plates of 40 permeability. The plates are supported upon rubber gaskets and are held in place by aluminum anchor bolts and clamps. They are therefore removable without danger of injury for cleaning or for any other purpose.

The outlets from the tanks are over weirs and through 42-in. venturi meters to channels leading to the final sedimentation tanks. The weirs are mounted on each side of steel troughs 13½ ft. in length. They provide therefore a length of weir of 54 ft. per tank. Channels are aerated with a single line of plates so that no deposits will form. The time re-

quired for sewage to pass all aerated channels is approximately 20 minutes when the works are operating at their desired capacity.

The capacity of air compressors and piping is sufficient to supply 1.2 cu. ft. of air per gallon of sewage but it is expected that much less than this amount will be required.

Final Settling Tanks

There are four rectangular final sedimentation tanks, shown in Fig. 6, each 134 ft. long, 93 ft. 9½ in. wide and with a water depth of 12 feet.

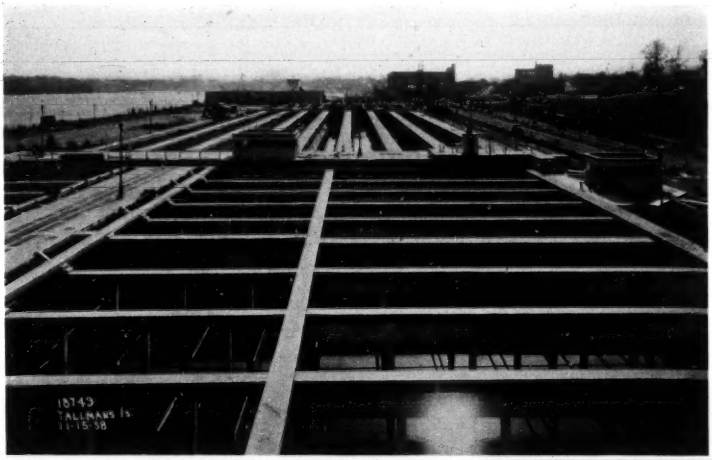

Fig. 6.—View of plant looking south from final settling tanks.

The period of retention is 2½ hours with 40 M.G.D. and 25 per cent returned sludge. The gross settling rate per sq. ft. per day is 1,000 gallons. In order to secure as good distribution as possible, sewage is admitted over a continuous line of weirs extending along the ends of the tanks on each side of the distribution channel. A line of baffles which may be raised, lowered or varied in width or position is placed in front of the weirs so that the best distribution may be secured. Five straight-line main collectors and one cross collector in each tank remove the sludge to pits located at a central position between the tanks.

Sludge is removed from the pits through four 20-in. pipes laid below the bottoms of the tanks to air lifts at the southwest corner of the tanks. The maximum allowable depth of sludge accumulated in the tanks is shown by a photoelectric eye which will flash a red light at the small register building near the air lifts.

Six weir troughs each 73 ft. in length and supported upon lines of columns between the sludge collector channels and on the side walls

receive the purified effluent and discharge into the effluent channel at the end of the tank. The troughs supported by interior columns have adjustable weirs on each side. The troughs at the side walls have one line of weirs. There is therefore 730 ft. of weirs in each tank. The head of the weirs is approximately ½ in. at the mean flow of 40 M.G.D. plus 10 M.G.D. return sludge. The effect of wave action and velocity of approach are very nearly eliminated and effluent is taken only from the uppermost and best clarified layer of water in the tank.

Walkways of wood are provided over each trough for convenience in weir adjustment observation and adjustment. Cooling water for the engines in the pump and blower house is taken by gravity from the effluent channel.

Four 16-in. air-lifts located at the southwest corner of the aeration tanks raise the return sludge about 4 ft. to sludge boxes, from which the return sludge flows to the return sludge channel and the excess sludge flows to the thickening tanks. A 12-in. air main from the main air line in the pipe gallery supplies air to the air-lifts through a 6-in. riser from each air lift. Sludge is lifted into sludge boxes 6 ft. square by 9 ft. deep. Each air-lift is provided with air adjustable metal hood or umbrella which acts as a splash plate and by which the amount of sludge lifted may be changed and equalized. Each sludge line leading to an air-lift is provided with a by-pass and valve by which any sludge box may be emptied for the purpose of adjustment or repairs.

Sludge Thickening Tanks

Since activated sludge has a high water content, it is advisable to attempt to reduce this before sending it to the digesters in order to cut down digestion capacity. For this reason, attempts have been made to thicken sludge in various ways. At this plant, two thickening tanks have been installed.

The thickening tanks are 24 ft. in diameter and 18 ft. side water depth, with shallow conical bottoms. They are fitted with slow-moving, stirring apparatus operated by a small electric motor. Sludge is retained in these tanks 12 hours and its water content is expected to be reduced from 99 per cent to approximately 95 per cent. Four tanks will be required for this purpose. Two only have been built at this time. They have a center feed. The thickened sludge is pumped back to the digestion tanks through the same main that carries the primary sludge. Supernatant water accumulates to a depth of 3 or 4 feet and is discharged over circumferential weirs to the outlet sewer. The long period of retention would ordinarily permit activated sludge to bulk, create a nuisance and escape over the weirs. To prevent this, it has been found effective to chlorinate the supernatant water. Chlorinators have therefore been provided for this purpose and chlorine is applied through pipe lines over the surface of the tanks with discharge nozzles located as nearly as practicable at regular intervals about the surface.

Chlorinators are located on the upper floor and sludge pumps on the

basement floor of the small building between the tanks. Very few tanks of this kind have been built and operating data by which results can be accurately predicated are meager.

Sludge Digestion Tanks

There are four sludge digestion tanks, each 83 ft. in diameter with side water depth of 30 ft. and conical bottoms 9 ft. in depth, with a useful volume of 176,000 cu. ft. each, or a total of 705,000 cu. ft., equivalent to 2.43 cu. ft. per capita. They are fitted with Downes floating covers. The digesting sludge will be maintained at a temperature of about 85° F. by four coils of 3-in. pipe carrying hot water and supported about 4 ft. from the outside walls and below the landing ledge of the covers. Hot water for heating is obtained from waste engine jacket water supplemented when necessary by water from boilers heated by sludge gas.

Gas which collects under the tank cover enters a gas dome, built as a part of the cover. It enters a gas pipe at a point several feet above the top of the dome and is carried to a small mixing tank in the pump and blower house, from which it is piped to the engines. Where the gas pipe leaves each tank, a flame trap, gas drip and meter are placed in the line.

Supernatant water is drawn from four levels. Apparatus is provided for sampling the water before it is drawn. This apparatus is placed in a ventilated gas-tight enclosure to avoid odors in the enclosed space between the tanks, and also the danger of explosion if gas escapes.

It is expected that about 50 per cent of the power required to operate the works will be obtained from sludge gas.

Fully digested sludge will be pumped to storage tanks located near the pier at which sludge boats will be loaded. The space between the digestion tanks which is entirely enclosed contains four sludge pumps, each of 130 g.p.m. capacity, whose principal function is to deliver digested sludge to the storage tanks. They can be used, however, to remove sludge from one digester to another when it is necessary to enter for any purpose. A chemical dry-feed machine with pump and hose connections to incoming sludge lines is located in this same enclosure, making it possible to treat sludge entering any digester with lime.

Supernatant water drawn to the supernatant settling tank can also be treated with lime or other chemical in the same manner. Two chlorinators are also provided for use with the supernatant settling tank. The depth of sludge in each tank will be shown on a register which is operated by a metal cable which passes over the tank walls and is attached to the floating cover. The whole enclosure is thoroughly ventilated and adequately lighted.

There are entrances on all sides of the enclosure and platforms for the delivery and removal of materials. All outside piping required in connection with the operation of the tanks is enclosed in pipe trenches, below the floor of the operating chamber, which are covered with metal grating.

Supernatant Settling Tank

The supernatant water settling tank is 20 ft. square with 20 ft. side water depth and a pyramidal bottom 5 ft. deep. It is covered with a concrete roof with entrance manhole with perforated cover. It is fitted with an adjustable settled effluent draw-off pipe and sludge suction line, connected to the suction line of the sludge pumps, and effluent weirs.

Supernatant water from the digestion tanks is discharged by gravity directly to the supernatant settling tank where it is retained 6 hours, treated chemically and suspended matter is allowed to settle. The partially clarified effluent is then discharged into the pump well and again sent through the works. The sludge from the tank is pumped back to the digestion tanks.

The supernatant water carries with it a quantity of suspended matter which is not fully digested but the quantity is small, the gas produced by it in this tank is not large and no provision has been made for capturing it.

Normal water level in the tank is above the level of the pump room floor so that the sludge pumps for the digestion tanks are self-priming from this tank so that no additional pump for the removal of this sludge is necessary.

Sludge Storage Tanks

The sludge storage tanks are 35 ft. in diameter and 29 ft. maximum side water depth, with conical bottoms. The capacity of a sludge boat is approximately 55,000 cu. ft. The tanks contain somewhat more than one boat load above the level of the conical bottoms. One boat load will be accumulated in about 5 days when the sewage flow reaches 40 M.G.D.

The sludge boats which now remove sludge from Wards Island will be utilized to perform a similar service here. Sufficient space is available near the sludge storage tanks to process sludge for fertilizer if at some future time it is decided to dispose of it in this manner.

Sludge is discharged from the storage tanks by gravity through a 14-in. main which is supported under the floor of the pier. Boats may be loaded from either side of the pier. A sludge pump located in the building enclosure between the tanks is for the purpose of emptying the sludge main after boats are filled, and for moving sludge from one tank to the other.

Sludge level indicators and facilities for removing supernatant water are also located in the building. Supernatant water, the quantity of which will be small, may be returned to the drain leading to the wet well.

Dock and Outfall Sewer

A steel sheet bulkhead was erected around the site to confine the fill and a concrete deck wood pile dock 300 ft. long by 34 in. wide was built for mooring of the sludge boats. The main plant outfall is carried underneath the dock.

Power

It is expected that about 50 per cent of the total power required will be available from the sludge gas, and the balance will be made up by purchasing gas and electricity from the local utilities. Electric power is used mainly for the plant auxiliaries, lighting, sludge handling equipment and ventilation. Current used is 3 phase, 60 cycles, 208 volts. There are 50 motors, which range in size from 1/6 to 40 H.P., of the totally enclosed, fan-cooled ball bearing type. The total connected H.P. of the motors is 425.

There are 24 ornamental standards for outside lighting and 1,000 watt flood lights for the pier. The total lighting load is 75 K.W. The total installed gas engine power is 3,500 break H.P.

Construction Cost

The project was financed wholly by the City of New York at a construction cost for the plant of $3,833,216, itemized as follows:

Contract 1.	Pier and Bulkhead	$ 334,780
Contract 2.	Structures and Equipment	1,303,064
Contract 3.	Pump and Blower House and Grit Chamber	1,280,185
Contract 4.	Mechanical Equipment—Pump and Blower House	469,000
Contract 5.	Electrical Equipment	199,126
Contract 6.	Heating and Ventilating	73,291
Contract 7.	Plumbing	48,990
Contract 8.	Roads and Landscaping	71,900
Contract 9.	Floating Covers for Digestion Tanks	46,280
Contract 10.	Sludge Thickening Mechanism	6,600
		$3,833,216

The above figures do not include the cost of land and it must be borne in mind a sizable proportion of the above construction will serve the ultimate plant. Pro-rating the above expense over the ultimate plant, the construction cost per M.G.D. is approximately $75,000.

The design and supervision of construction was started under the jurisdiction of the Department of Sanitation and was completed by the Department of Public Works.

The officers and engineers charged with the responsibility of carrying out this work are as follows:

Irving V. A. Huie, Commissioner, Department of Public Works; R. H. Gould, Acting Deputy Commissioner; Walter D. Binger, Deputy Commissioner, Department of Sanitation; J. Frank Johnson, Chief Engineer, W. Donaldson, Director, Bureau of Sewage Disposal; Henry Liebman, Designing Engineer, Edwin J. Fort, Project Engineer, Victor Greiff, Electrical Engineer, J. W. VanDenburg, Mechanical Engineer. The construction was supervised by H. C. Gaffney, Construction Engineer, A. R. Glock, District Construction Engineer, and A. Williams, Resident Engineer.

Special credit must be given to Mayor LaGuardia whose keen appreciation and co-operation has greatly advanced the progress of sewage treatment in the City of New York.

EXPERIMENTAL VENTILATION OF THE NORTH OUTFALL SEWER OF THE CITY OF LOS ANGELES *

By E. G. Studley

Supervisor, Bureau of Engineering, City of Los Angeles

The North Outfall Sewer of the City of Los Angeles is 55 miles long from its upper end in Canoga Park, located in the westerly end of San Ferrando Valley, to the screening plant at Hyperion. The lower 6-mile section which was constructed in 1924, was sealed as far as normal ventilation was concerned from the rest of the system by a siphon under Centinela Avenue and has only one large connection which is the force main from the Venice Pumping Plant. This section of the outfall was built with very few manholes and these were sealed so that the sewer operated without any appreciable change of air from 1924 until 1936. Air samples in 1936 contained as little as 11.7 per cent oxygen.

In 1936 openings were cut in the top of the sewer at intervals of from 300 to 2,000 feet which were used in connection with the inspection of this section of the sewer by Reuben F. Brown, Assistant Superintendent of Sewers. (See *This Journal*, Vol. 9, p. 446 (1937).) The major result of this inspection was that some means must be adopted to reduce or eliminate the disintegration of North Outfall Sewer.

This sewer, which is of semi-eliptical cross section 10 ft. 6 in. high and 12 ft. 3 in. wide at the spring line, was lined above the spring line with clay liner blocks. The joints between the liner blocks were kept as narrow as possible and filled with Portland cement mortar.

The inspection in 1936 found large areas of the sewer without tile; found the joints between the tile to be reduced to a mushy gypsum and the concrete where tile was off to be soft and porous. From the condition of many tile which were reported as spalled, it was apparent that there had been no failure of the tile but that the reduction of the joint and concrete back of the tile from concrete to gypsum had forced the tile off, either as a unit or in pieces.

The problem, therefore, was to eliminate the hydrogen sulfide gas, prevent its oxidation to sulfuric acid, or the accumulation of the acid on the concrete.

Since this sewer has an average flow of 200 cu. ft. per second, the control of hydrogen sulfide with chemicals would have been very expensive. The alternatives were the submerging of the sewer with control gates, or ventilation.

On February 24, 1937, the Board of Public Works adopted the City Engineer's report recommending experiments be conducted in ventilating a portion of the North Outfall Sewer and the first appropriation was made by the Council in August, 1937.

* Presented at a Meeting of the Sanitary Engineering Group of the American Soc. of Civ. Eng., Los Angeles, Dec. 6, 1938.

Two methods of ventilation were considered. First, the forcing of fresh air into the sewer at one location and the release of air from the sewer at intervals along the sewer, which is the method used by Melbourne, Australia. This method has the advantage that the fan is not subject to corrosion. The second method, which was adopted, was the evacuation at one point, admitting fresh air at intervals along the sewer. This method was adopted for experiment because the station could be located about a half mile west of Centinela Avenue where the top of the outfall is just below the ground and was accessible for trucking heavy machinery. It is also the farthest removed from any developed section so that it was probable that the sewer air could be released into the atmosphere without being deodorized and without complaint.

This location is 2,000 ft. below the Centinela Siphon and 31,000 ft. above the screening plant. It is also adjacent to the section of the North Outfall which showed the greatest deterioration. The principal objection to the location was the fact that electrical energy could be had only for an expenditure close to $5,000, which was considered out of the question for experimental purposes.

Therefore, a 6-cylinder Diesel engine salvaged from a caterpillar and mounted on a special frame with outboard bearing and clutch was rented. An evacuating fan with a rated capacity of 15,000 cu. ft. per minute was also rented. These rentals provided that if the city desired to purchase the equipment, the rent paid would apply on the purchase price. The fan was connected to the top of the sewer by a long radius elbow and a short sleeve of 36 in. diameter. The perpendicular discharge line from the fan was built of sheet iron and is 18 in. by 20 in. in cross-section. The engine was mounted on a heavy concrete mat, with adjustments for alignment, and connected to the fan with a 12 in. flat belt. The unit was enclosed in a sheet-iron building (Figs. 1 and 2).

Two 400-gallon fuel tanks were installed with gravity feed to the engine filter which provided sufficient storage for a week's supply of fuel on a 24-hour per day operating basis. The flat belt drive was the only troublesome unit of the assembly and has since been replaced with a triple roller chain and geared sprockets which run in an oil bath in a metal housing.

Actual ventilation started Jan. 3, 1938. For some time daily records were kept of the following items:

Fan speed.
Quantity of exhausted air.
Wet and dry bulb temperatures of the exhaust air and atmosphere.
H_2S content of the exhausted air.
Amount of vacuum in the suction line.
Quantity of air admitted at the various openings in the sewer.

The quantity of air admitted was controlled by adjusting the sliding doors on the wooden covers placed on top of the openings cut in the sewer for the 1936 inspection. The interior condition of the sewer has

been inspected from time to time from wooden platforms lowered through these inspection openings and the use of mirrors to direct light into the sewer, but no further investigation has been made by boat between openings.

Ventilation was put on a 24-hour per day basis two days after starting. The variation of inlet locations has never required over 1.7 inches of water suction on the fan so that at the normal fan speed of

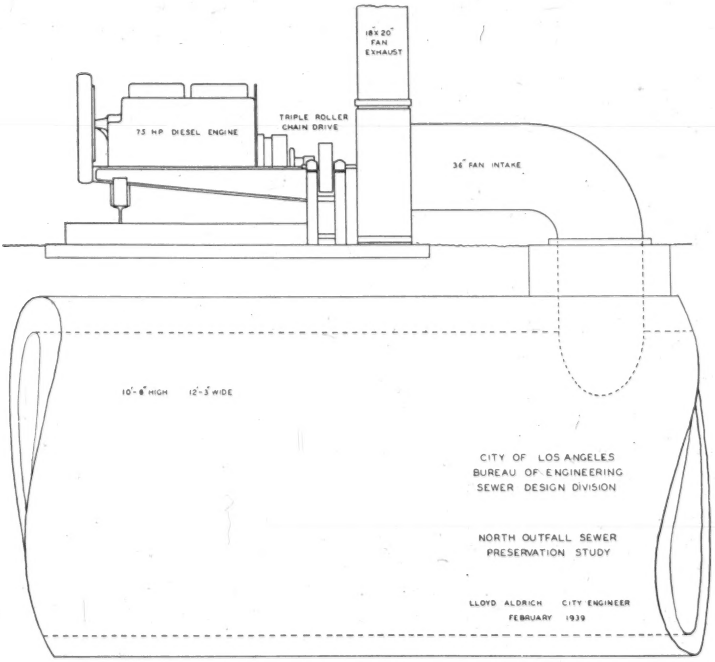

FIG. 1.—Sketch of sewer, fan, intake and exhaust.

850 r.p.m. the quantity of air removed has remained consistently about 22,000 cu. ft. per minute. The location of the fan is designated as Hole 1 and all openings downstream are numbered consecutively.

For the first five days of operation all fresh air was admitted through Holes 4 and 6, 1,176 and 2,400 ft., respectively, from the fan. In these five days there had been considerable drying out of the sewer adjacent to the holes open but at the unopened holes the sewer was very wet.

During the next week all fresh air was admitted through Holes 8 and 10, 4,350 and 5,375 ft. respectively, from the fan. At the end of

this second week the sewer adjacent to the holes which had been open the week before, had lost its relatively dry condition and was very wet again. The sewer between the holes which had been open this week, namely Holes 8 and 10, was drying out nicely and at intermediate Holes 7 and 9 was showing the effect of ventilation.

It was decided at this time to open all holes from 3 to 10, leaving 2, which is only 330 ft. from the fan, closed for observation purposes. This was done Jan. 18, 1938. A canvas curtain was installed in the sewer adjacent to Hole 15 and Hole 16 was opened so that air from the lower portion of the sewer displaced by the rise in sewage level would be forced out at 16, and not be sucked into the ventilated portion.

By the latter part of February the entire length of sewer from the fan to Hole 10 had changed in appearance and the benefits of ventilation were being noted.

FIG. 2.—General view—object left to right—exhaust pipe, H_2S testing equipment, fan, stack, drive belt and engine (picture taken before completion of building.)

On Feb. 28 and on March 2, 1938, this portion of the sewer was running under a head. On the latter date water overflowed from out ventilation inlets in several places, cutting away the earth bank to a dangerous degree. Because of the press of emergency flood clean-up work, ventilation was not resumed until March 14, 1938. After the storm, overflow pipes were installed at Holes 7, 8 and 9 so that further inspection at these locations was impossible. (See Table I for data.)

By the 1st of May, the sewer from Hole 10 to the fan, a distance of 5,375 ft., was covered with a greyish or yellowish powder and the material between the tiles was dry and hard. Another 2,000 ft. westerly from 10 had been open a week.

On Sept. 1, 1938, the ventilation section was 10,200 ft. long and on Nov. 1 was 12,570 ft. long. Since that time Hole 18 and the siphon outlet structure have been opened, making the ventilated portion 14,200 ft. long.

Prior to ventilation the air temperature in the sewer was about 80° F. The sides of the sewer were covered with a wet stringy deposit con-

taining 7 per cent CaO, 4 per cent SO_3, and 12 per cent metal trioxides. The inner surfaces of the sewer had sufficient free moisture on them so that the drops of water gathered and ran down the tiles and joints carrying the gypsum out of the tile joints onto the tiles below.

As the sewer dried out the surface deposits were dried first and disappeared, leaving the sewer very new looking. The free water disappeared and the tile joints had the consistency of putty. However, when the tile was rubbed with a squeegee drops of water could be

TABLE I.—*North Outfall Sewer Ventilation*

Observers A. A. Appel and J. J. Buehler. Operating Records, Typical Day. Date 3/28/38

Time	Atmosphere			Exhaust Gas					Suction, Inches of Water	Discharge from Fan			Remarks
	Dry, F.°	Wet, F.°	Hum., %	Dry, F.°	Wet, F.°	Hum., %	H_2S, p.p.m.	Fan Speed, R.P.M.		Velocity Pressure	Velocity, Ft./Sec.	Quantity, C.F.M.	
8:00	58	54	78	68	68	100		832	1.3	4.5	144	21,600	Weather—cloudy and cool.
9:00	61	55	68	68	68	100		825	1.3	4.5	144	21,600	Reinserted plaques in Nos.
10:00	63	55	61	68	68	100	8	828	1.3	4.6	146	21,600	2 and 6. Looked in Hole
11:00	62	54	60	68.5	68.5	100		828	1.3	4.5	144	21,600	15 and saw that baffle was
12:00	63	55	61	69	69	100	6	834	1.3	4.6	146	21,900	still hanging in good condi-
1:00	60	53	64	69	69	100	8	838	1.3	4.4	143	21,450	tion. No water has been
2:00	64	56	61	69	69	100	7	838	1.3	4.5	144	21,600	thrown out of stack today
3:00	64	57	65	69.5	69.5	100		835	1.4	4.5	144	21,600	
4:00	56	51	71	69.5	69.5	100		825	1.3	4.4	143	21,450	

Air Inlet Quantities

		Hole No.	3	4	5	6	7	8	9	10	16	Total
		Dist. from Fan, Ft.	720	1,176	1,919	2,401	3,421	4,357	4,865	5,373	10,359	
		Area, Sq. Ft.	1.5	1.5	1.87	2.25	3.14	3.14	3.14	6.88	3.88	
A.M. 10:00–11:00		Anem. Vel.	1,300	690	570	740	615	655	650	410		
		Correction	−107	−44	−35	−49	−40	−42	−42	−9		
		Ave. Vel., Ft./Min.	1,193	646	535	691	575	613	608	401		
		Quantity, C.F.M.	1,790	969	1,000	1,555	1,805	1,925	1,909	2,438		13,391
P.M. 2:00–3:00		Anem. Vel.	1,630	1,740	1,250	1,255	1,000	1,040	785	345	210	
		Correction	−142	−156	−102	−102	−76	−81	−51	−3	+17	
		Ave. Vel., Ft./Min.	1,488	1,584	1,148	1,153	924	959	734	342	227	
		Quantity, C.F.M.	2,232	2,376	2,177	2,594	2,901	3,111	2,305	2,353	881	20,930

gathered. After this, the joints would become firm and hard and the tile had a yellow deposit of sulfur on it. To the hand the deposit on the tile felt greasy. Subsequently, the tile became very dry and was covered with a grey or white powder. This powder has been washed off the sides of the sewer which are alternately submerged and exposed throughout the day. There has been sufficient drying during the hours of low flow to eliminate the line of saturation, the high flow line being the limit of the powder. I refer to it as a powder, even though it may be greasy or moist, to distinguish it from the original deposit.

At each inspection hole, the driest and wettest condition exists. I believe the inlet air should be funneled into the sewer to eliminate the condensation which we have experienced on the downstream side of the holes where the sewer air first comes in contact with the fresh air. This area of condensation extends only a few feet downstream from the hole and we have been governed by the condition of the sewer below this point.

Since January, 1938, there has been no record of an exhaust humidity below 100 per cent. There have been humidities in the sewer recorded at 95 per cent but I think the air admitted at the hole during the time of the sampling affected the work.

The last exhaust air samples taken (Table II) averaged 16 p.p.m. H_2S between 10:00 A.M. and 3:00 P.M. The last sewage sampled throughout the ventilated section for H_2S was taken in the middle of April and averaged only 2 p.p.m. where originally the sewage had 10

TABLE II.—*Atmosphere and Exhaust Gas Data Taken at North Outfall Sewer Ventilation Station*
Tests made by Los Angeles Bureau of Standards, Sept. 1, 1938

Time	Exhaust Gas			Air	
	Hydrogen Sulfide (H_2S) (p.p.m.)	Temperature (° F.)	Relative Humidity (per cent)	Temperature (° F.)	Relative Humidity (per cent)
10:00 A.M.	15	80	100	74	77
11:00 A.M.	17	80	100	74	73
12:00 M.	17	80	100	74	73
1:00 P.M.	16	81	100	75	70
2:00 P.M.	16	81	100	76	70
3:00 P.M.	16	81	100	74	73

p.p.m. The cross-sectional air space in the sewer varies from 41 to 76 sq. ft. and the average velocity in the sewer at the ventilation station is 300 feet per minute.

As additional holes are opened it is gratifying to see that the sewer is drier than it has ever been before and we are confident that even though we are attempting now to ventilate less than half of the North Outfall Sewer from Centinela Avenue to the Screening Plant, the effect of our work is extended to possibly the entire distance.

The operating cost of the Diesel engine has proved to be economical. The daily requirement for fuel is about 70 gallons, which is delivered to us at 3¾c per gallon, and 3 gallons of lubricating oil, which provides for oil changes twice a week. The power requirement of the fan is 55 H.P. so that the 75 H.P. engine operates at 625 r.p.m. without effort. This station will operate this fiscal year for $2,000.00, exclusive of labor, barring another accident which required the rebuilding of the starter engine.

Even though the exhausted air from the sewer contains 16 p.p.m. of hydrogen sulfide and is fully saturated, no deterioration has occurred

to paint on the fan, or the discharge line, which is built of galvanized iron. There have been no complaints from the neighborhood relative to objectionable odors being exhausted from the sewer, and neither has there been more than the faintest odor detected anywhere in that vicinity when the fan was operating. Time after time I have been in the district, along the sewer and at the station, without detecting any sewage odor.

The evacuated air is discharged into the atmosphere with a velocity of 150 ft. per second, and whether the dilution obtained at this high velocity keeps the odor within reasonable bounds, or whether there is an actual oxidation of the gas as it strikes the atmosphere, is not known; however, we have operated throughout the year without any effort toward controlling the odors from this ventilating system.

The entire condition of the outfall is so greatly improved that it is the recommendation of the City Engineer that this station not only be maintained, but that other stations be constructed so as to ventilate both the North Outfall and Central Outfall, at least from Crenshaw Boulevard westerly.

This work has been carried on with appropriations made for this purpose by the City Council, under the jurisdiction of Lloyd Aldrich, City Engineer, and under the immediate supervision of H. G. Smith, Engineer of Sewer Design, with installation and operation being performed under the supervision of F. A. Batty, Superintendent of Sewers, and with the co-operation of T. A. Fitch, Director of the Los Angeles Bureau of Standards.

SYMPOSIUM ON SEWER RENTALS*

I. SEWER RENTALS

By R. C. Sweeney

District Sanitary Engineer, State Department of Health, Albany, N. Y.

Sewer rentals or the establishment of rates for the use of a sewer system are not new in the United States. The plan has been in use since 1894, when Brockton, Massachusetts, passed a sewer rental ordinance which is still in effect. A recent survey has indicated that there are now more than 600 municipalities in 35 states which utilize this plan for financing the operation of sewage treatment plants.

New York State, although one of the 35 states that have an enabling act which permits municipalities to utilize a plan of sewer rental, has not yet taken much advantage of the plan, for there are only two municipalities in the state which actually have sewer service charges in effect.

The New York State act enabling municipalities to set up a charge for the use of the sewer system is quite broad in that it permits that the funds so obtained ". . . shall be used for the payment of the cost of the management, maintenance, operation and repair of the sewerage system, including treatment and disposal works, and any surplus in such fund may be used for the enlargement or replacement of the same and for the payment of the interest on any debt incurred for the construction of such sewerage system and for retiring such debt. . . ."

Other features of the law are that the governing board of the municipality may: (1) base the rate schedule on any equitable basis, (2) change the schedule from time to time, (3) keep the collected funds separate and (4) apply the rentals as a lien on the real property served and when in arrears such rents may be collected as other delinquent taxes.

The act does contain one prohibition, that is, that the funds so derived shall not be used to extend the sewer system into unsewered areas.

While the basic act which permits municipalities to utilize a sewer rental plan of financing was passed in 1929 the two cities actually having the plan in effect in New York State have not used the act of 1929 but have used the provisions of two later acts passed in 1935, one the so-called "Revenue Bond Act" of that year, the other the act setting up the Buffalo Sewer Authority and prescribing its duties and powers.

The Revenue Bond Act, which is Act 14C of Chapter 525 of the laws of 1935, was devised to assist in the financing of self-supporting and self-liquidating undertakings of all kinds. The act specifically mentions such undertakings as tunnels, bridges, docks, water supply developments, sewers and sewage treatment works. The act provides for the issuance of bonds for the improvement and the establishment and collection of rates, fees, tolls or charges for the service provided by the

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undertaking. It further provides that the revenues collected shall be used for:

(*a*) Debt service on the improvement.
(*b*) To provide for all expenses of operation and maintenance of the undertaking, and
(*c*) To provide a reserve for improvements to the project.

The major defect of the Revenue Bond Act is that the bonds for the improvement must be sold to the Federal Government.

The provisions of the Buffalo Sewer Authority act relating to the establishment of sewer rental follow to a certain extent the provisions of the general law of 1929 in that the act provides:

1. That the rates must be on an equitable basis.
2. That the rates may be changed when deemed advisable, and
3. That the charges if not paid shall become a lien on the property served which can be foreclosed by the Sewer Authority.

The first of the two municipalities of New York State to utilize sewer rental was the City of Plattsburg, whose ordinance went into effect in February, 1938, though under a special provision of the ordinance only one-half of the scheduled rates were collected for the year 1938. Plattsburg has a population of approximately 14,000 and while the city owns and operates its water supply, only a limited number of meters are in use. Its schedule of sewer rents therefore could not be based on the metered use of water and a flat rate charge depending on type of premises served was utilized.

The schedule of rates at Plattsburg includes the following charges:

Type of Premises	*Annual Charge*
Single Residence	$ 6.50
2 Family Residence	8.00
3 Family Residence	9.00
4 Family Residence	10.00
5 Family Residence	11.00
6 Family Residence	12.00
7 Family Residence	13.00
8 Family Residence	14.00
9 Family Residence	15.00
10 Family Residence	16.00
11 Family Residence	17.00
12 Family Residence	18.00
14 Family Residence	20.00
17 Family Residence	23.00
Public Schools	0.00
Private Schools	0.00
Churches	0.00
Creameries	50.00
Garages—Washing Cars	25.00
Filling Stations—Washing Cars	12.50
Green Houses	15.00
Hospitals	50.00
Hotels—75 Rooms or more	50.00
Hotels—Less than 75 Rooms	25.00
Laundries	25.00
Public or Business Toilets	5.00

Provision is made by the ordinance to collect the sewer rental quarterly, the amount due being shown as a separate item among a number of other items which appear on the single city tax bill. Payment for the use of water is also included as one of the items on the tax bill.

The Plattsburgh ordinance was designed to meet all of the operating charges against the new treatment works which are now under construction, and in addition to provide funds to meet the annual bond and interest charges against both the treatment works and the new intercepting sewers. The estimated cost of maintenance and repair of the local and intercepting sewer systems have not been included. The estimate of the annual revenue desired was $20,900 made up of the following items:

Plant operation	$ 6,500
Interest on debt	5,400
Bond retirement	9,000
Total	$20,900

From the four 1938 collections, during which only one-half of the scheduled charges were collected, the city obtained approximately $10,750, which would indicate no difficulty in meeting the budget requirement. Additional leeway is provided in that the collections to date have not included payment for sewer service for the United States Army Barracks at Plattsburg, the sewage from which will be handled under a separate contract calling for an annual payment of about $500.

Basic data for the establishment of the rate schedule was secured by means of a house-to-house survey by three city employees. From the survey a master card covering each service was prepared and these are available in case of any inquiry relative to the charge imposed. The municipal officials have reported that very few objections have been made to the plan and that the majority of objections were withdrawn when the plan was thoroughly explained. Much of the credit for the success of the plan is said to have been due to the careful handling of the proposal during its early consideration.

The Buffalo rate schedule went into effect on July 1, 1938, after a very thorough study by the Authority and the Authority's consulting engineers, Greeley and Hansen of Chicago. The basic plan of the Buffalo schedule is one that has found favor with a number of municipal officials in that it derives revenue not only from rentals but also from direct taxation. The grandfather of all charges for sewer service, the 1894 Brockton, Massachusetts plan, is of that type, 60 per cent of the revenue being obtained from sewer rentals with 40 per cent being obtained by direct taxation.

Such a plan is especially applicable where the revenue obtained is used not only for treatment works operation but also for debt charges against the sewage treatment works or the interceptors or both. In the event that funds are derived only from the actual users of the sewer system the owner of vacant land pays nothing for the benefit of having the improvement available when he does require it nor does he con-

tribute for the general benefit that comes to the municipality from having sewerage and treatment facilities provided.

In the Buffalo situation there is even more reason for raising a portion of the desired revenue by direct taxation, because of the fact "(*a*) That part of the total annual revenue . . . is required on account of storm water" and "(*b*) That part of the total annual revenue . . . is required to provide capacity for future growth and thus to add security to vacant property." On that basis the Buffalo plan provides that 45 per cent of the Authority's revenue will be obtained from a general property tax, the balance of 55 per cent from sewer service charges.

In Buffalo all of the large consumers of water are metered, the majority of the small consumers being charged on the basis of their frontage, number of plumbing fixtures or other factors. Each of these classes of consumers contributes about one half of the Water Department's revenue.

The revenue plan of the Buffalo Sewer Authority is designed to furnish approximately $1,500,000 per year for the following purposes:

Salaries	$ 396,211.72
Office Supplies	14,272.00
Transportation	22,930.00
Billing	33,007.08
Repairs and Supplies	198,464.95
Power	74,180.00
Chemicals	86,000.00
Insurance	22,900.00
Debt Service and Reserve	601,900.00
Contingent Fund	50,134.25
Total	$1,500,000.00

The sum of $675,000 or 45 per cent of the budget, is now collected as a property tax by means of a separate annual billing by the Authority. It is anticipated that in the future this tax, which in 1938 amounted to approximately 73 cents per thousand dollars assessed valuation, will be billed and collected by the regular taxing authorities.

The balance of the budget, amounting to $825,000 per year, is being raised by sewer rental charges based on water usage. The area served by the works of the Authority contains a population of about 600,000 which are served by approximately 18,000 metered and 85,000 flat rate water services. Metered water services using more than 250,000 cubic feet monthly are billed every month, with quarterly collections from the remaining metered services. Flat rate services are billed semi-annually. Billing for sewer service based on water usage follows the collection schedule of the Division of Water, the single bill issued containing separate items for water and sewerage service. The bills are payable at the office of the City Treasurer.

The resolution of the Buffalo Sewer Authority setting up the schedule of rates provides for a number of different bases of payment:

(*a*) Up to 9,000 cubic feet per quarter	$.40 per 1,000 cubic ft.
9,000 to 18,000 cubic feet per quarter	.28 per 1,000 cubic ft.
In excess of 18,000 cubic feet per quarter	.16 per 1,000 cubic ft.
Minimum charge	.80 per quarter.

(*b*) For churches, public hospitals, schools, colleges and city departments, etc., $.016 per 1,000 gallons.

(*c*) 40 per cent of the water bill for flat rate services with the provision that no charge shall be made for water used for lawn sprinkling, automatic sprinkling systems, rock gardens and other miscellaneous uses where the water is not returned to the sewer system.

(*d*) Provision that when city water is not used the owner of the premises shall install a meter at his own expense and that the payment for usage shall then be made in accordance with the schedules in (*a*) or (*b*) above.

(*e*) A provision that when a property uses in excess of 3,000 cubic feet of water per quarter and it can be shown that all or a portion of the water used is not returned to the sewer system the Authority may require or permit the installation of additional measuring devices to determine the flow entering the sewer system.

(*f*) A provision that when in the opinion of the Authority the sewage or waste contains an unduly large concentration of waste which adds to the cost of treatment of the sewage the Authority may elect to establish a special rate.

(*g*) That $675,000 shall be collected from all taxable real estate in the City of Buffalo.

Interest will be charged at a rate of 6 per cent per year on all rentals not paid when due.

Collections to date have generally met expectations and indicate that the budget requirements will be met. Representatives of the Authority state that considering the number of billings made few objections have been filed.

While the Buffalo and Plattsburg rental plans are the only two actually in effect in New York State at present, one of the college communities in the central part of the state late in 1938 proposed a sewer rental plan which was to have gone into effect on January 1st of this year. The ordinance was based on the enabling act of 1929 and proposed a rate schedule based on 38 per cent of the gross water bill. It was proposed to collect the rental charges at the same time and in the same manner as were the charges for water. Other provisions of the ordinance were that:

(1) The Board of Public Works was to determine and fix an equitable rate for premises having sewer connection but obtaining all or a part of its water supply from other than the city supply.

(2) Water used but not returned to the sewer system could be deducted.

(3) The unpaid rents become a lien on the property, and

(4) The funds derived might be used for all sewerage purposes except the extension of sewers into unsewered areas.

An interesting section of the proposed ordinance is that it provides that any one permitting water specifically metered for commercial or non-sewage purposes to return to the sewer system would be *guilty* of *disorderly conduct.*

The water rates of the municipality are in part as follows:

Quarterly Meter Service Charge		*Usage Charge per Quarter*	
5/8 in.	$.50	1,000 cubic feet	$ 3.50
3/4 in.	.55	2,000 cubic feet	6.10
1 in.	.60	3,000 cubic feet	8.40
1¼ in.	.65	5,000 cubic feet	12.55
1½ in.	.75	10,000 cubic feet	20.70

Local objections have been made by establishments that have their own water supply, particularly the educational institution, and the ordinance has temporarily been tabled by the municipal officials.

The collegiate episode just related has been added only to give more weight to our limited New York State experiences with this plan. It should be recognized, however, that in the two municipalities actually using the plan there are approximately 615,000 people, which after all is a sizable group of people. Their experiences with sewer rental to date have been generally satisfactory and those of us concerned with sewage treatment in this state hope that the plan of sewer rental will be carefully considered by the many of our local municipal officials who could well use an assured and adequate fund for the operation of their sewerage systems and treatment works.

II. COMMENTS ON SEWER RENTALS*

By Robert A. Allton

Consulting Engineer, Division of Sewage Treatment, Columbus, Ohio

The first point I wish to discuss is a criticism of the title of this paper: namely the use of the word "Rental" in connection with a charge for sewer service. This may seem like a minor point but, in our case, it has caused much misunderstanding and a small amount of opposition to this method of raising funds for the operation of sewerage works. Those who drafted the enabling legislation used the word in accordance with accounting practice to mean a charge or income. However, to the man in the street "Rental" is a payment which he makes for something which he rents and uses, such as a house or an apartment. Consequently, when the sewer rental ordinance was passed, we were immediately asked this question—"Why should citizens pay rent for the use of the sewers and sewage treatment works when the city already owns them and is paying for them with tax money?" Starting with this attitude they then proceed to tell us that to pay rent for something which they already own is to pay twice for the same thing. We have had to take every opportunity to explain that a sewer rental charge is not rent in the popular sense but is a direct charge for a service rendered. However, even after a year's operation, this question still comes up and causes some dissatisfaction. Where this method of financing is

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to be discussed with the general public, I urge that you avoid the word "Rental" and call it a sewerage charge or other appropriate name whose meaning is clear.

There are many different methods of making a sewerage charge but by far the most popular, at least in Ohio, is to base the charge on the water consumption. This discussion will therefore be devoted to a consideration of this method.

The use of water consumption as a basis for a sewerage charge is predicated on the assumption that the quantity of water used is a measure of the quantity of sewage produced. This assumption is not strictly correct and if rigidly adhered to would result in individual charges all out of proportion to the use of the sewerage system. For this reason, when a sewer rental ordinance is drawn, provision must be made for exempting from charge water which does not and cannot enter the sewer system. In the case of industrial plants, this will necessitate a survey of each plant to determine the percentage of metered water that enters the sewer and, once this percentage is determined, it is applied to each meter reading to obtain the quantity of water on which the sewer charge is based. With domestic accounts, the question of exempting from payment water used for sprinkling is usually brought up. In the preparation of a sewer rental ordinance I have recently had occasion to make an investigation of this point. A study of a large number of domestic accounts indicates that the excess water used during the four summer months of June, July, August and September varies from 8 per cent of the total annual consumption for accounts with a total annual consumption of 12,000 gallons to 6 per cent for accounts with a total annual consumption of 60,000 gallons.

In the preparation of a schedule of rates for this method of making a sewerage charge, it is necessary to know the percentage of the total quantity of metered water which will be exempt and while accurate figures are not yet available, it would seem that 25 per cent is not far from correct.

Another important point in the preparation of a schedule of rates is the quantity of water that enters the sewerage system from private water supplies. It is usually impossible to determine this with any degree of accuracy. However, if each private water supply is provided with an approved meter, this meter can be read and the sewerage charge computed in the same manner as for the accounts using the municipal supplies.

In any discussion of this method of making a sewerage charge, the point is usually raised that the charge should be based not only on the quantity but also on the strength of the sewage delivered to the sewer. That this is true cannot be denied but I think its importance is overstressed. The difficulty of obtaining correct samples and the enormous amount of analytical work which would be required would be almost prohibitive. Furthermore, in any city the industries that produce wastes of abnormal characteristics are usually known and can be made the subject of special agreements.

When setting up a rate schedule, provision should also be made for delinquent accounts or else the money actually received will be less than the amount required. Our experience indicates that between 10 and 15 per cent of the amount billed is delinquent at the end of the year.

Arguments are still advanced that the cost of operation of sewerage works should be paid by general taxation rather than by a special sewerage charge, on the theory that the sewerage works are a general benefit to the public and the charge should be based on the ability to pay rather than on the amount of service received.

So far as my experience goes this contention is not borne out by the facts and, if anything, the small user of water pays less under a sewerage charge than he would if the cost came out of general taxes. Furthermore, where funds are raised by taxation all tax-exempt properties, such as county and federal buildings, would pay nothing toward the cost of operation of the works whereas under a sewerage charge they do. It may be argued that the charges paid by these properties is itself raised by taxation and this is true but these taxes are levied on an area far greater than the city limits and therefore tend to decrease the amount which the inhabitants of the city will pay.

III. SEWER RENTALS*

By W. F. Tempest

Highway and Municipal Bureau, Portland Cement Association, Chicago, Illinois

Perhaps a discussion of sewer rentals should start with a definition of the term and its purpose. I prefer the term "sewer service charges" which seems a little more explanatory. We may consider sewer rental as a charge for utility service in proportion to demand, use and benefits. It has been my experience that those who are familiar with essential services performed for municipalities are generally in favor of the principle of charging in proportion to use. For the use of any utility service, whether it be electric power and light, telephone, waterworks or sewerage, the most equitable charge is on a basis of demand and use. It is a little strange that in the sewerage field we seem to have had some difficulty in gaining the wide acceptance of this principle that has been so readily accepted without question for other utilities, as for example electric power and light and even the very close relative of sewerage—waterworks. Perhaps it is because the other utilities bring something to us rather than take something away from us. We are more conscious of the pleasure and convenience of turning on the faucet for a glass of water or a refreshing shower than we are of the service performed in disposing of the waste water. Those who have always enjoyed the advantages of modern plumbing do not appreciate the difficulties suffered under the pioneer "draw and carry" method of taking

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a bath when it was necessary to draw the water from the well, carry it in and carry it out. I am recalling this picture merely to illustrate the point that the full advantages of good waterworks system can only be enjoyed when there is a complete sewerage system for disposal of the waste and spent waters of a community. This fact needs to be driven home in selling the public on the idea of sewerage as an important utility service for which a specific charge is justified.

When general taxation is the sole means of raising funds for the construction and betterment of sewerage facilities there is an injustice in charging those who do not receive the service the same as those who daily enjoy its use. It is true that the value of vacant property is enhanced by the availability of sewer service, but no more so than that of the users of the service. Owners of vacant property should pay some form of ready to serve charge and this can be provided for at the time the rate schedule for sewer rentals is established.

There are many phases to the sewer rental method of financing but for the purpose of this discussion I think we can group them into five or possibly four classifications:

First—Legislation
Both state and local.

Second—Publicity
Educational campaign to overcome objections.

Third—Rate Schedules
Selection of basis for charge best suited to the peculiar conditions of the municipalities. This is perhaps the most important phase of sewer rental study.

Fourth—Billing Methods and Collections
Possibly a separate item for discussion should be made for "Collections." Under "Billing Methods" may be discussed a standard billing form and time such as monthly, quarterly, semi-annual or annual. Under "Collections" we may discuss penalties, discounts, property liens, etc.

Legislation.—The sewerage works associations can be of particular assistance in examining state legislation and recommending changes for a workable law and thereby making its benefits more widespread. I believe that your association is the largest and while there is no particular virtue in bigness alone, I have it on good authority that you are the most active and influential, and I know personally that you have accomplished a great deal in this state. If my information is correct you could profitably work for improvement of the sewer rental law in New York to broaden the scope of its provisions and to include specifically construction costs which item I understand is not definitely provided for.

I believe it would also be to your advantage and to the benefit of numerous municipalities in the state to have enacted a law authorizing the issuance of sewer revenue bonds so that it would not be necessary to have special legislation such as was required for Buffalo. You have, I believe, taken a definite stand in your state constitutional program

confining the payment of revenue bonds strictly to the income derived from the service. That is as it should be, provided that there exists sufficient power in the statutes to enforce adequate rates and payment. Our studies show that 35 states have some form of legislation that will permit sewer service charges and in five more states charter provisions, or other special circumstances, of certain municipalities permit them to charge sewer rentals. Although this would indicate fairly wide legislative provision, comparatively speaking, little use has been made of it. I think there are two principal reasons for this: one, fear that the legislation is inadequate, and two, general misunderstanding on the part of officials and the public.

Publicity.—I should like to emphasize the need for educational campaigns because this is something that is often neglected or poorly done. Factual data honestly and convincingly presented will smooth the way for acceptance of the sewer service charge principle. Not only that, but intelligent publicity will create the necessary public demand for sewage treatment and sewerage extensions. This is demonstrated in a recent report of the Division of Sanitation, New York State Department of Health. Public meetings were held and conferences arranged by the Department with municipal officials, who in some cases were taken on an inspection trip to other communities to view the design and operation of sewerage works.

Rate Schedules.—No matter what method is used in charging for sewerage the problem of making an equitable distribution of the cost is a difficult one. It has long been realized that direct property assessment alone is not a suitable method. The sewer rental method is being considered more and more as the most reasonable solution. A number of municipalities are using what may be called a compromise method as best suited to their present conditions. This takes different forms. In some cases service charges are made for repair, maintenance and operation, and the capital cost of the sewerage works carried by the general property tax. In others the entire cost of the treatment works is financed by service charges and the existing collection system carried by general tax.

Methods of charging for sewer service offer a wide variety of choice. Writers on this subject have listed about 18 different methods. Two fundamentals should be kept in mind in discussion of sewer rate schedules. First, of course, the rate should be adequate to meet all requirements and must be determined by engineering studies. Second, allowing for a reasonable margin of safety, the rates should not be in excess of requirements which might create the danger of funds being raised by this method to pay other costs of government. We all know of cases where other utility rates, as for example electricity and water supply, have been made to carry part of general government functions. This practice is inequitable and defeats the very purpose of the service charge principle.

Some years ago the New York State Bureau of Municipal Information compiled a summary of existing methods for determining the rate

to be charged for sewerage service. I am repeating the list here for convenient reference.

1. A graduated scale depending upon the quantity of water consumed. A minimum charge is usually fixed.
2. A uniform rate for all consumers based upon water consumption.
3. A charge equivalent to a certain percentage of water bill.
4. A "ready-to-serve" charge in combination with graduated scale based on water consumption. This charge may be graded according to number of fixtures.
5. A flat rate per connection according to a classification of property.
6. A rate based upon the number of fixtures connected to the sewer system.
7. A combination of a flat rate and a rate per fixture.
8. For industrial sections rates may be based upon number of persons employed or served.
9. A rate based upon quantity and quality of sewage contributed as determined by B.O.D. test.
10. A rate based entirely on the measured quantity of sewage contributed. This would require individual meters or weirs.

This summary does not include possible charges against the property which may be used in combination with those listed.

From a recent survey made in more than 100 municipalities in various parts of the country the rate was generally based on the amount of water consumed. In most cases this was obtained from metered water consumption. Unless some other method is used in combination with this there is no measure of the quality of the sewage discharged. A survey of the number and kind of fixtures and the average flow from each will provide a basis for fixing a rate in proportion to both quantity and quality of the discharge of each user.

Some communities merely add a fixed percentage to the water bill but it is preferable to make a separate charge even though it may actually be a percentage of the water bill. The trend seems to be toward the use of a graduated scale based on the metered water consumption. This is particularly desirable for monthly or quarterly billing.

In Oak Park, Illinois, where sewerage improvements have recently been completed and financed on a sewer rental and revenue bond method the schedule of charges is as follows:

		Per Quarter
Up to and including	9,000 gallons	$ 1.50
9,001 to	15,000 gallons	1.75
15,001 to	20,000 gallons	2.00
20,001 to	30,000 gallons	2.50
30,001 to	50,000 gallons	3.00
50,001 to	70,000 gallons	3.50
70,001 to	100,000 gallons	4.00
100,001 to	150,000 gallons	4.50
150,001 to	300,000 gallons	6.00
300,001 to	450,000 gallons	7.50
450,001 to	750,000 gallons	9.00

	Per Quarter
750,001 to 1,000,000 gallons	10.50
1,000,001 to 2,000,000 gallons	16.50
2,000,001 to 3,000,000 gallons	22.50
3,000,001 to 6,000,000 gallons	40.50
6,000,001 to 9,000,000 gallons	58.50

The above rates are based upon the consumption in the first quarter of each calendar year. This avoids complaints of excess charge when water is used for lawn sprinkling.

It is of interest to note that of the 11,500 accounts on the books of Oak Park, 2,600 pay the minimum charge $1.50, 3,600 come within the second step, and 1,800 in the third group.

Billing.—Billing methods should be as simple as possible and in many cases can be worked out in co-operation with the waterworks department. No additional expense need be incurred because of sewer service charges. It may even be possible to effect some economy by the purchase of a billing machine for use in handling both waterworks and sewerage bills.

Monthly billing appears the most painless method of collection with quarterly billing the next choice. Semi-annual and annual statements are submitted in several municipalities but these seem to have more of the appearance of a property tax bill and do not as effectively convey the idea to the user that he is paying for a specific service of daily convenience.

If the charge is made on a combined water and sewer bill it is desirable to show each charge separately and somewhere on the bill the schedule of rates or the basis for the amount should be shown. A common practice on all utility accounts is to show this on the reverse side. It would be distinctly helpful if some agreement could be reached on fundamental recommendations on billing forms and methods so that at least within each state there would be some degree of uniformity in accounting practice.

The question of collections brings up a number of points on which there are differences of opinion. Can the water be shut off to enforce payment of sewer charge? Can the sewer be stopped for non-payment? Can a penalty be imposed? Is it possible to place a lien on the property served? What does the State Board of Health have to say about the imposition of any penalty? What recourse do the bond holders have? These are some of the questions that are asked when discussing the subject of collections. Often the difficulties feared are more theoretical than actual and by and large municipalities operating on a sewer service charge basis have an excellent record of collections and delinquencies are not a serious problem.

It is only natural, of course, that when a bill is first received for a service which the user has not previously been conscious of paying, he will raise some objection. This is particularly true if no educational campaign has been conducted and the ordinary citizen has not been informed of the necessity for the increased facilities.

Shutting off the water or the sewer are considered drastic measures not permitted by Public Health authorities in so many cases that it is wise to consider other possible means of enforcing payment. The state law should be so worded that a lien for the amount due can be placed against the property served. This is an effective method and generally the most applicable. A penalty of a certain per cent of the bill, if not paid on or before a stipulated time, is also a common method that has been effective in many places.

IV. FINANCING SEWAGE TREATMENT BY SEWER RENTALS*

By M. W. Tatlock

Superintendent, Sewage Treatment, Dayton, Ohio

The success or failure of any sewage treatment plant depends in the greatest measure upon whether or not it is operated in a skilled fashion; and provision for its proper operation and maintenance usually involves two main considerations: personnel and finance. These items are closely related, because without proper financial provisions technical supervision and skilled operation are impossible. The degree of financial provision for operation, then, usually dictates the degree to which the sewage treatment plant is scientifically operated. The personnel may vary, as determined by budget provisions, all the way from regularly employed technically trained and experienced men to the very non-technical or laborer class of operator, or even to no regularly employed full-time operation. Municipalities in some states (notably Ohio and Pennsylvania) are confined within certain statutory limits of expenditures for both construction and operating funds. The need for proper financing is advisable and necessary in all states.

A survey in Ohio in 1928 showed that less than 10 per cent of the sewage treatment plants were being operated under technical supervision, that probably less than 20 per cent were giving satisfactory service to protect the receiving streams from nuisance and undue pollution conditions; that the polluted stream conditions were caused by failure of the sewage treatment works, and that the neglected operation was traceable to inability to finance operations from current revenues. Effort to enact new laws on taxation to give more revenues generally failed but if new laws were passed the budgeted items for sewage treatment were usually the last to be taken care of, even though the cities might be forced to pay damages for conditions created by the neglect of the sewage treatment works, because damages are a preferred charge against a municipality and do not come within the ordinary bond and tax limitations. However, surprising and untrue as it may seem, municipalities offered to build plants without knowing exactly where the funds would be found to operate them. The reason was usually based on a desire to hold off damage claims and embarrassing injunction suits.

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The Ohio Law

The Ohio statutes provide that the Department of Health may require the construction of sewage treatment works to protect the public health, and shall approve all plans for sewage treatment works and require information on the operation after they are built. When it was observed that an order of the department might be nullified if the municipality did not have sufficient funds for operation of a plant under the order, the department adopted the policy of refusing to approve plans for new treatment works unless there was reasonable assurance that sufficient funds would be provided for the correct maintenance and operation of such works. It was for this reason that the department requested the passage of the sewer rental law enacted in 1923. This was the first law of the kind to be passed. It is an act permitting municipalities to assess and collect charges for the use of sewers and to provide for the proper maintenance, operation, and control of sewerage systems and sewage disposal works. Any municipality may, under this statute, operate its sewerage department upon a utility basis and make it self-supporting by equitable charges for sewerage and sewage disposal service. The law provides for this in the following manner: Ohio General Code Sec. 3891–1–2–3–4–5 and Sec. 4357.

> The council of any city or village which has installed or is installing sewerage, a system of sewerage, sewage pumping works, or sewage treatment or disposal works for public use, may by ordinance establish just and equitable rates or charges of rents to be paid to such city or village for the use of such sewerage, a system of sewerage, sewage pumping works, or sewage treatment or disposal works by every person, firm or corporation whose premises are sewered by a connection to such sewerage, system of sewerage, sewage pumping works, sewage treatment or disposal works. Such charges shall constitute a lien upon the property sewered by such connection and if not paid when due shall be collected in the same manner as other city and village taxes.
>
> This fund shall be used for the payment of the cost of management, maintenance, operation and repair of the sewerage system and sewage pumping, treatment and disposal works, and any surplus in such fund may be used for the enlargement or replacement of the same and for the payment of the interest on any debt incurred for the construction of such sewerage system and sewage pumping, treatment and disposal works, and for the creation of a sinking fund for the payment of such debt, but shall not be used for the expansion of a sewerage system to serve unsewered areas or for any other purchase whatsoever.

Other provisions of the Act designate what officials shall be responsible for the administration of the law, when and with whom the funds shall be deposited, and that it may be spent only when appropriated by the council and upon the order of the director of public service of a city or the board of trustees of public affairs of a village.

The Plan Develops

Sewerage works are past the convenience stage. Recreation, health, and conservation in all its phases demand that all waters, after they have been turned to waste, shall be disposed of without complaint from anyone, just as the public demands a pure and wholesome water supply for its general use. If a water works is to be considered a public

utility, and it is generally conceded to be one, then its "poor relation," the sewage treatment plant, must be one too. If the water works can be made self-supporting by a schedule of rates, is it not logical to conclude that it is just as necessary to provide similar funds to remove the used water from our premises as it is to bring pure water into them? The sewer rental laws adopted by the various states recognize this consideration of the question.

The idea is not new. The City of Brockton, Mass., had been making and collecting such charges successfully since 1894. The general use of the law has developed slowly but it seems to have passed from the experimental stage. The demand for some legal provision for participating in Federal aid projects has caused several states to pass enabling acts which permit a sewer rental charge to place the project on a self-liquidating basis. The construction of some plants has been financed entirely from mortgage revenue bonds to be retired from the charges assessed for the use of the sewers and treatment plant. This plan usually results in a high rental charge. It has been reported in *Public Works* that there are now 35 states which have enabling acts and that cities in 9 of the 13 remaining states which have no enabling act, are successfully charging and collecting sewer rentals either through special charter provisions or through their interpretation of the general state laws.

This municipal publication sent a questionnaire in 1936 to every city which was known to have a sewage treatment plant and approximately 2,000 answers were returned. These answers showed that only 167 cities out of the 1,128 reporting from the states with enabling acts were using the sewer rental laws available. These cities ranged in population from 480,000 to only 179 inhabitants. This report would indicate that relatively few of the cities reporting were taking advantage of the state laws permitting the charging of sewer rentals as a method of financing improvements to the sewerage systems and to provide more adequate treatment of these municipal wastes. A more recent review of sewage rental practice has been completed by the Portland Cement Association and reported in the Dec. 1, issue of the *Engineering News-Record*. A comparison of this report with the report made in the "Municipal Index," 1938 Edition, on data collected in 1937, indicates that there has been a decided increase in the adoption of this method of financing, notably in the larger cities. Cleveland and Columbus, Ohio, and Buffalo, New York, are good examples.

Basis of Charges

Sewer service charges have been collected on a great variety of bases and established rate schedules have been set up so that they cover: (1) the fixed charges on the construction of the collection system and treatment plant and also their operation and maintenance expense, (2) the fixed charges on the construction of the treatment plant and the operation and maintenance of the plant and collection system, with the construction cost of the collection system paid from general taxation,

and (3) the operation and maintenance cost of the collection system and treatment plant. In every case the rates include the administrative and collection costs. While the statutes may permit the inclusion of all fixed charges and operation and maintenance costs in the basis for a rate schedule, it is generally agreed that every sewerage system is a benefit to the health of the whole community, that it likely serves areas not now developed, that it will be paid for before its design capacity is reached, and that its useful life should extend into the future beyond the life span of present users. Therefore, it is unfair to charge to the present users the cost of the fixed charges incurred in the construction. It is also agreed that any owner is benefitted by the sewer laid by his land and that he must be benefitted by having it maintained in an operating condition. A sewer rental charge against his property is, then, a just and equitable charge. While there is a general agreement that the amount of water used, with allowances for that not returned to the sanitary sewers, is a reasonably accurate base for the payment for the use of sewers and treatment works, there is a wide variety of methods in use, as indicated by the following reports:

A study made by the City of Minneapolis showed 18 different methods in use as a basis of charges, one-half depending partly or entirely on the amount of water used and one-half depending on factors independent of the amount of water.

The 1938 Public Works Engineer's yearbook reported a recent study of over 125 towns and cities in 22 states, which showed that 22 towns and cities had a uniform annual flat rate per connection varying from $1 to $12, 16 towns and cities based the charge on a per cent of the water revenues and these varied from 10 to 100 per cent, 30 towns and cities had a flat or graduated scale based on the volume of water used, one city had the charge based on the biochemical oxygen demand, 7 cities had the charge based on the type of sewer connection, three on the type of buildings, and over 50 upon the number of plumbing fixtures or outlets, and in some of these cities there was a different charge for different types of fixtures, with minimum charges ranging from $2 to $8 per annum.

The report of a survey of sewer rental practices made by the Portland Cement Association (*Public Works,* Dec., 1938) covering 92 municipalities shows that the rate basis employed in 35 cities was the amount of water consumption and that this was modified in 8 others. Among these modifications were: Water consumption for commercial use and flat rate for residences, sewer rate combined with water rate, water consumption to the extent that it discharges into the sewers, water consumption plus a flat rate and connection charge, and a rate based on winter month consumption. The flat rate was used in 29 cases, the number of fixtures was used in 18 cases, and others used special devices such as 55 per cent by water consumption and 45 per cent against real estate. This report covered cities in 17 states ranging in size from Buffalo, N. Y., with 560,000 population to Lawrence, Neb., with 528. Fifty-two were under 10,000 population.

The volume feature may become more important with the installation of air-conditioning units. This uncontaminated water should not be permitted in the sanitary sewers but its discharge into existing storm sewers may severely overtax their capacity. Should not consideration be given to charging for the discharge of such waters, from whatever source, into the storm sewer system of a municipality the same as for the discharge of sanitary sewage into the sanitary sewers?

It is apparent from these reports that no set rules can be applied in choosing a basis for charges. Each municipality will have its local problems and the method chosen must not only suit these conditions but it must provide an adequate revenue to meet the charges against it, administrative and collection expense must be held to a minimum, and the cost to all uses, both domestic and commercial, must be as fair as possible.

In considering the reports previously referred to it must be considered that they are based on the answers to questionnaires, and how many really consider such a request very seriously? While these reports indicate that there are relatively few municipalities making use of this method of financing sewerage systems and sewage treatment works, there are several hundred cities in the entire United States and over 200 in Texas alone. The experiences with the collection have been more favorable than anticipated. Of the cities reporting on the question of delinquencies in the Portland Cement Association report, 9 reported "none," 11 "very small," 14 others less than 5 per cent, and only 3 over 10 per cent. Dayton, Ohio, with 48,500 accounts recently reported less than one-half of 1 per cent of its accounts to be delinquent. The answers in this report regarding protests against the charge would indicate that the question of protests is more imaginary than real, for of the 92 municipalities reporting, only 6 noted more or less serious protests, 4 protested at first, 10 filed slight protests, and 12 reported no protests of any kind. In the *Municipal Sanitation* Round Table (Sept. and Oct., 1936) these questions were asked:

1. Do you use sewer rentals for financing the maintenance and operation of sewers and sewage treatment works?
2. Do you feel that this method of financing would provide more adequate funds for your services?
3. How would your residents react to such a tax?

Only 6 of the 31 replies came from municipalities using the sewer rental and of these 6 only 1 reported an unfavorable reaction and this answer stated that the reaction was passing. However, 11 not using the plan, thought that the public reaction would be unfavorable. Fifteen of those reporting thought that if they were using the plan that more adequate funds would be available and 2 thought the opposite.

The same publication in the Dec., 1937, issue asked these questions in the Round Table Discussion:

1. How do you finance sewer and sewage works operation and maintenance?

2. If the sewer rental method is used, has the plan met with public approval?

There were 38 answers to these questions; 26 used the sewer rental plan, 8 used taxes, 2 billed water and sewer services as a water bill, 1 just added 50 cents a month to the water bill, and 1 used taxes for sewers and the sewer rental for the treatment plant. There were, then, really 30 using the plan. Twenty-six reported the plan entirely satisfactory, one questioned the adequacy of the plan, one reported not quite enough funds. The most critical statement was, "the plan was not 100 per cent approved."

Advantages of the Plan

The plan will provide funds for construction when other sources of funds are exhausted. Municipalities in practically all states are limited to a certain bonded debt and total taxes which may be assessed. These limits have obstructed the orders of state health departments in requiring the construction of sewage treatment facilities to correct pollutional nuisances. The use of the sewer rental laws makes it possible to finance such improvements outside legal limitations of bonded debt and taxes. Bonds issued under the sewer rental law are not a general obligation of the municipality and are not counted against its debt limitations. The law is flexible enough to provide an equitable and moderate method of financing for any city which really wants sewage disposal and also will provide the funds necessary for successful operation.

The sewer rental plan should result in lower operation costs. A large part of taxes is used to pay for the performance of special services —sewerage, street paving, cleaning and lighting, refuse collection, fire and police protection, and others. If our taxes were used only for the expenses of government proper, they could be materially reduced. But how would we pay for these special services? The answer is to recognize them as a utility and charge for the service in the same manner that gas, electricity, telephone, and water services are charged. As has already been pointed out, the laws of 35 states now permit such charges and changes in a few state laws would permit all to do so. It might be argued that the gross total of all utilities rates and taxes for governmental uses might be no less than under the present plans of operation, but the writer believes that the proportion paid as utility rates would generally be paid with less protest, should it total no less than the taxes, and that there are possibilities of the total being less. If the manager of the utility knew that his failure to operate it economically meant an increase in rates to all the citizens, instead of an increased allowance by a budget committee, he would likely to be more careful about his expenditures. It is also economical because it is a "pay-as-you-go" plan.

The plan will furnish adequate funds, and provide them continuously. Not much argument can be presented against any plan which will make it possible for the plant superintendent to be sure there are

always funds available. He can plan his operations so that major expenditures can be spread over a period of years and feel sure that such plans can be economically carried out, without competition from more popular budget items than sewage disposal, or entire deletion by economy cuts of disinterested budget officials. The superintendent supplied continuously with adequate funds can maintain his plant in an efficient condition and thereby avoid waste of public property. There will be no question about efficient operation, because the funds are available for engaging trained operators and adequate labor.

A well drawn sewer rental ordinance will provide a sense of security. Good operation will avoid the danger of lawsuits because of pollution from the discharge of untreated sewage or other nuisance which might result under conditions of bad operation. The law provides that "surplus funds may be used for the enlargement or replacement of present works, etc.," and that the funds shall not be used for any other purpose whatsoever." The honest administrator of such a fund may accumulate a surplus for some specific purpose or to care for an emergency expenditure.

The Dayton situation illustrates this point well. The primary treatment plant was approved by the State Board of Health, for construction in 1928, with the provision that secondary treatment devices should be planned for by 1935. With this provision in mind, annual surpluses in the fund were allowed to accumulate, with the result that in 1936 this surplus exceeded $100,000. This was the nest-egg which made possible a Federal W.P.A. grant of sufficient funds to construct, during the past three years, a secondary treatment plant costing $1,350,000, and the fund balance is still almost $100,000. And again, when the recent disastrous gas explosion wrecked the Imhoff tank pipe gallery and control houses, the funds were available to carry on the reconstruction without resorting to some scheme of financing which might have caused delay in the work.

Excessive administrative and collection costs are not necessary for the collection of the funds. If the charge is based on the amount of water used, the machinery for billing and collecting the fund will already be set up and only require expanding to serve both utilities. The Dayton Ordinance, covering 48,500 accounts, was put into effect by the installation of mechanical billing equipment and the addition of one clerk in the billing division of the Department of Water.

The law is just because it bases the charge for service on the user in proportion to the use he makes of the sewers serving his premises.

The writer wishes to acknowledge and express his appreciation to the authors of the articles, and the publishers of the articles referred to in this paper and also to Mr. F. O. Eichelberger, City Manager, and Mr. W. W. Morehouse, Director of the Water Department, The City of Dayton, who permitted this absence from his municipal responsibilities.

Stream Pollution

LEGAL ASPECTS OF STREAM POLLUTION *

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Stream pollution has been a legal problem virtually since the beginning of civilization. It was recognized as such in the civil law and in the common law, and there is now a vast American jurisprudence on the subject.

Important as are legal measures and the application of legal principles to the control of stream pollution, they are no more significant than are proper administrative procedures, competent technical developments, effective public education, and adequate financial provisions. All of these factors are interrelated, and all are necessary elements in the successful solution of this public health problem.

Legal doctrines regarding stream pollution are now well established in this country. On the one hand, they involve the power and duty of the State to protect and preserve the health of its citizens, while on the other they are concerned with the rights and responsibilities of individuals with respect to the use of waters and water courses.

Stream Pollution as a Nuisance

At common law, every riparian owner was entitled to a reasonable use of water flowing by or through his property in a natural stream. He did not own the water, but the use of it was a prerequisite of his ownership of the land or soil. The riparian owner was entitled, further, to have the stream come to him with its quantity undiminished and its quality unimpaired. This right was subject, however, to the reasonable use of the water by riparian owners above him.

This general rule of law still holds good. It means simply that the use of a stream by each person must be consistent with the rights of others. These rights have been expressed in two ancient legal maxims, *sic utere tuo non alienum laedas* ("so use your own as not to injure another's"), and *aqua currit et debet currere, ut currere solebat* ("water flows and ought to flow as it has been accustomed to flow").

A material alteration in the quality of a stream by pollution with sewage, industrial wastes, or other noxious or unwholesome matter is not a reasonable and proper use of it. Such pollution constitutes a nuisance, for which there are remedies in law and equity. The person whose private rights have been infringed in this way may sue at law for damages, or seek to have the continuance of the nuisance enjoined

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by a court of equity. The equitable remedy of injunction affords relief where the legal remedy of damages fails to give permanent and satisfactory relief.

The perpetrator of the nuisance may be an individual, a private industrial corporation, or a municipal corporation, against each of which the injured person has a proper cause of action in cases of gross or unreasonable pollution. Ordinary draining of surface water into a stream is generally regarded as a proper use of it, but the discharge of sewage and waste by artificial means into a watercourse is usually held to be an immoderate and illegal use of the stream.

The fact that a manufacturer who pollutes a stream is engaged in an important industry representing a large investment does not excuse him from liability for injuries to individuals, no matter how humble. At one time the courts of Pennsylvania espoused the principle that coal mining in that state was an industry so necessary to the general welfare that persons who were damaged by mine wastes in streams must suffer the injury without compensation. This peculiar doctrine was not followed by the courts in most of the other states, and finally was more or less repudiated in Pennsylvania. In this state, as in all other states, pollution of streams by sewage is held to be a public nuisance, dangerous to the public health.

Where an individual, whether a natural person or a corporation, commits the nuisance of fouling a stream, the fact that others are also polluting it will not excuse the individual, although the fact might mitigate the amount of damages assessed in a lawsuit.

Liability for such a nuisance does not cease or diminish with the passage of time, for no one can obtain a prescriptive right to cause a nuisance of this character. Custom never sanctions the doing of that which is a legal wrong. The right of harmless pollution of a stream may sometimes be obtained by prescription, but not the right of harmful pollution.

Liability of Municipal Corporations

A municipal corporation, such as a city or incorporated town or village, is in general liable for the creation and maintenance of a nuisance in the same manner and to the same degree that an individual is liable.

While the construction and institution of a sewerage system is generally held to be a governmental function of a municipal corporation, the operation of sewage works and the disposal of sewage is not a governmental but a proprietary or corporate function of the municipality. In the conduct of its governmental duties, a municipal corporation is never liable for damages due to the improper acts of its officers and employees, but it may be liable for injuries arising out of the exercise of its corporate or business operations.

The protection of water supplies to prevent contamination and to conserve the public health is a governmental duty, but the furnishing of water for domestic consumption is a proprietary function. Thus, if

municipal employees drive cattle from a watershed, the city will not be liable for injuries to them, as a rule, but if a municipal water supply becomes contaminated with sewage due to the negligence of the municipal officials, the city will be liable for all cases of disease which are actually caused by this water supply. The same principle applies to private water companies.

Neither a municipal corporation nor a private water company is a guarantor of the purity of the water that it furnishes to consumers, and there is no implied warranty that the water is pure, as there is in the case of the sale of food. On the other hand, the city or company must use all reasonable precautions to prevent dangerous contamination of its water supply, and will be liable for injuries if it knowingly furnishes impure or unwholesome water to a consumer who is unaware of the danger. The city or water company is also liable for negligence in supplying impure water, provided that there is no contributory negligence on the part of the consumer.

The rule that a municipal corporation is liable to individuals for the nuisance of stream pollution and for injuries caused by the improper or unsafe disposal of sewage has been sustained by courts of last resort in this country on numerous occasions.

The only exception to this rule is in the case of the discharge of sewage into tidal waters. Since the state and its political subdivisions, such as cities, have the right to dispose of untreated or treated sewage in tidal waters, it has been held that a city is not liable for damages to growers of shellfish or others injured by this practice, in the absence of legislation imposing such liability.

Where private parties drain sewage and industrial waste into public sewers or a sewerage system owned and operated by a municipal corporation, they are, in general, not liable for damages caused by the improper disposal of the sewage effluent. The municipality is liable in such cases, although there might be instances in which a large industrial concern has made an unreasonable use of a small sewerage system, and could be held to be liable, in part at least, for the ultimate damage to others. Where a city and a manufacturing plant each discharge sewage and wastes into a creek, they may be held independently, but not jointly, liable for resulting injuries to individuals. Whoever exercises the power of control over the discharge of sewage is the one who is liable for harm resulting from it.

In determining the question of negligence in the operation of a sewage disposal system or a waterworks, the negligence can usually be presumed if violation of a state law or a municipal ordinance can be shown. This principle applies equally to individuals, corporations, and municipalities.

Legislative Control of Stream Pollution

If there were no legislation pertaining to stream pollution, the common law rules would provide ample legal redress for this nuisance. Not only is there the legal remedy of damages for injuries due to pollu-

tion, but there is the equitable remedy of injunction to prevent the continuance of the nuisance and even to enjoin a potential nuisance from this source. As a rule, however, the common law remedies are chiefly effective in dealing with stream pollution after it has become a fact.

Legislation, on the other hand, can be preventive in nature. Statutes can prohibit the pollution of streams and fix a penalty for this practice, which is usually stated by law to be a crime. By means of legislative enactments, administrative machinery is also created for the determination of this nuisance and for coping with the problem. The existence of legislation is, likewise, an incentive to municipal bodies to make appropriations for proper sewage disposal. Legislation is, therefore, a necessary supplement to the unwritten, or common law, that is now applicable to stream pollution.

Laws for the control of stream pollution are in force in every state. Such laws represent a valid exercise of the police power of the state, since they are enacted in the interests of the health, safety, comfort, and general welfare of the people. In dealing with these topics, legislatures possess plenary powers, which are subject only to certain constitutional limitations.

Statutes providing for the reasonable control of stream pollution, and imposing obligations and duties in this respect upon individuals and municipal corporations, have been frequently sustained by courts of last resort in this country.

Under its police power, the State may properly delegate to state and local health departments or other agencies certain necessary duties in connection with the enforcement of laws for the control of stream pollution. Having adopted broad legislation, the state may confer upon boards of health the power to promulgate rules and regulations to carry out the purposes of the legislative act. Such rules and regulations are not legislation, but they have the force and effect of law, and must be obeyed by all persons affected thereby.

So, too, the legislature may vest in an administrative board or ministerial official the power to determine the fact of stream pollution and to order its abatement, or actually to abate it according to law. In executing these laws, administrative officials must, however, adhere strictly to the terms of the law. Certain discretionary powers may be given to these officials, but other procedures may be definitely fixed and must be followed.

The state legislature may properly require that sewage disposal plants and waterworks be operated only by qualified persons who have been licensed by a competent state authority. The power of the state to restrict the practice of certain professions and the conduct of certain trades to those who are properly qualified by education, experience, and moral standards is now well established. Engineering and architecture are among the professions now generally subject to licensing in many states. In New York, the Public Health Council of the State Department of Health is given the power by law to prescribe qualifications for operators of public sewage disposal plants and water purification plants.

The control of stream pollution is primarily a state responsibility. The federal government is concerned with stream pollution only as it affects navigation in the navigable waters over which it has jurisdiction, or when interstate commerce is affected. The federal government is, however, keenly interested in this problem, and has made loans or grants of federal funds to assist municipalities in providing adequate facilities for the safe disposal of sewage. The Congress of the United States has also given its consent to various interstate compacts for the control of stream pollution where the interests of two or more states are concerned.

Conclusions

From this brief review of the legal aspects of stream pollution, it is obvious that the law on this subject is well established, and that the existing legal principles are adequate to take care of this phase of the problem.

The statutory law on the subject is likewise comprehensive, valid, and enforceable, although possibly in need of a certain degree of expansion and uniformity, which will, nevertheless, still permit of necessary adaptation to local conditions.

Law enforcement is, of course, an essential element in the conquest of stream pollution. Vigorous and forthright action by executive departments, especially in dealing with recalcitrant municipal corporations under existing laws, will gradually but surely bring about an improvement in the sanitary conditions of our streams and water supplies.

As stated at the beginning, however, law is but the background and solid foundation for the solution of this important public health problem. Of equal significance are the administrative, economic, and sociological aspects of the problem.

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Industrial Wastes

TREATMENT OF BREWERY WASTES

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Introduction

The Gulf Brewing Company of Houston, Texas, is located on the 75-acre tract of the Hughes Tool Company, makers of oil drilling tools, and is closely affiliated with the latter company through ownership and management. The industrial wastes from the two companies flow into a small stream known as the Country Club Bayou, about two miles above its junction with Bray's Bayou, a much larger stream. Gagings of the Country Club Bayou show that the normal dry weather flow is about 2.2 M.G.D., of which about 1.0 M.G.D. is clean cooling water from the Hughes Tool Company and 0.6 M.G.D. is wastes from the brewery. The Country Club Bayou is polluted by storm and other overflows from the city sewers above the brewery and from septic tank outlets below it. The time of flow to Bray's Bayou during the dry period was found by a dye test to be about ten hours.

Vigorous complaints have been made concerning the odors from the Country Club Bayou during the summer months. It was apparent that the brewery wastes could not be handled by the City of Houston's overloaded treatment plants, and it appeared probable that this condition might exist for some time. Consideration was also given to the possible harmful effects of a brewery waste on the activated sludge process at these plants. As a consequence, it was necessary that the brewery take care of its own wastes. An investigation into the possible methods of treatment was started in the summer of 1937.

Sources of Wastes

Diagram 1 is a flow sheet of the brewery processes and shows the wastes produced from the different steps. For convenience of operation the brewery is divided into three sections; namely, the brew house, the cellars, and the bottling and keg plant.

Brew House.—In the brew house the malt and rice are boiled separately in kettles with mechanical agitation. The mash is removed by pumping the liquors through a plate-and-frame press, and the filtered liquors are joined in the brewing kettle. Here the hops are added and the mixture boiled for several hours. The wort then passes through the "hop jacks" where the hops are removed by centrifugal action. The liquor is pumped to a storage or balancing tank at the top of the

building. While the next batch is brewing, the hot liquor from the storage tanks flows by gravity through cooling coils to the cellars using first well water and then brine for cooling.

The spent grain from the plate-and-frame press is dropped into a screw conveyor and conveyed to a storage bin outside the building. Through a gate in the conveyor most of the liquor is removed from the grain and flows into a tank. This tank is emptied to the sewer at a more or less uniform rate through a small pipe overflow. The spent grain is sold for cattle food.

The spent hops are blown by steam to a bin where they are allowed to drain, the drainage flowing through a small settling tank to the sewer. No use has yet been found for the spent hops and its disposal is somewhat troublesome.

Besides the drainage from the spent hops and spent grain other sources of waste are from the filter cloths, which are washed in a wash-

DIAGRAM I.—*Gulf Brewing Company Flow Sheet*

Flow	Process	Wastes
Rice-water Malt-water Rice kettle Malt kettle	Boiled 4.5 hours	Wash water
Plate and frame filter (Spent grain-cattle feed)	Grain removed	Drainage from grain. Filter cloth wash water
Brew kettle	Boiled 4.5 hours	Wash water. Lye waste
Hop jack (Spent hops)	Remove hops	Drainage from hops. Wash water
Balancing tank	Equalize flow to coolers	Wash water
Cooling coils	Cool wort	Clean cooling water
Fermenting vats	Fermented 10 days	Skimmings. Wash water
Yeast filter	Remove yeast	Filter cloth wash water
Storage tanks	Stored 3 months	Wash water
Filter	Remove solids	Filter cloth wash water
Bottling	Bottles washed in machine.	Wash water. Lye waste
	Kegs washed	Wash water.
Pasteurizing	Finished beer	Spillage

ing machine after each use, and from water used to wash the cookers, brew kettle, balancing tank and the various pipe lines.

The brew house has a capacity of five brews per day. Each brew produces 300 standard barrels of beer of 31 gallons each. A brew requires about 4.5 hours. The rest of the 24-hour day is occupied with a thorough scrubbing of the apparatus. A strong lye solution is used to scrub the copper kettle. The wastes from the brew house are warm. The well water supply is fairly warm, perhaps 75 to 85 degrees F., and further heating occurs from the boiling hot materials of the kettles. About 100,000 gallons of water per day from the brew house is hot clean water from the heat exchanger. If found desirable at some future date this water could be separated from the rest of the wastes.

The Cellars.—The cold wort passes to the steel fermenting vats in the cellars, where the yeast is added and fermentation continues for ten days at 39° F. Every day the vats are skimmed and the skimmings thrown on the concrete floor and washed to the sewer. After the fer-

mentation is finished the beer is filtered through a plate-and-frame filter to remove yeast, and goes to storage tanks where it is stored under pressure for three months at 34° F. It is then filtered again and pumped to the bottling plant. Excess yeast is removed from the fermenting vats by means of hand carts.

Sources of liquor wastes from the cellars are, the skimmings from the fermenting vats and water used to wash filter cloths, lines, vats and tanks. The wastes are quite cold.

Bottling and Keg Plant.—Bottled beer is preferred in this part of the country, so 90 per cent of the beer from this brewery is bottled. The returned bottles contain a small amount of beer. In the bottle washing machine they are first rinsed and then pass successively through a 2 per cent, a 4 per cent and a 2 per cent solution of soda ash, followed by about six rinsings and brushings.

The bottles go next to the filling and capping machines and thence through the pasteurizers, which wash off the small amount of beer that overflows during the filling. Labelling and placing the bottles in cases completes the process.

The caustic bottle wash solutions are removed and settled every day to get rid of labels and dirt. Every two weeks the solution is dumped and renewed. Wastes from the bottling plant consist of wash water from the bottle washers, spillage and breakage and water used for floor washing and cleaning. The amount of wastes from the keg washing is quite small. These wastes are fairly warm.

Amount of Wastes

During the operation of the pilot plant, a careful study was made of the amount of wastes from the brewery. The flow was measured by a weir, readings being taken every 15 minutes throughout the 24 hours. Samples were taken every 30 minutes. During the period from Jan. 14 to Feb. 18, 1938, the brewery was operating at capacity for five days per week, with two brews on Saturday and one on Sunday. Average results for this period are shown in Table I.

Table I.—*Amount of Wastes From Brewery*

	Average	Average, omitting Sat. and Sun.	Maximum Day
Flow, M.G.D.	0.48	0.53	0.68
24-Hr. B.O.D., p.p.m.	340	334	740
24-Hr. B.O.D., lb./day	1375	1485	3220
Suspended Solids, p.p.m.	371	368	1325
Suspended Solids, lb./day	1478	1630	4810

The brewery was operating at a high rate for winter at the time of the test. Normally the rate of operation varies from the capacity of 35 brews per week during the hot weather to as low as 30 per cent of capacity during the winter. The yearly average is about 70 per cent of capacity.

Throughout the investigation, 24-hour B.O.D.s were used. It was realized that these are not as consistent as 5-day B.O.D.s, but there was a great advantage in being able to follow the operation of the pilot plant more closely. Also in this particular case we were principally concerned with the stability of the effluent for ten hours after it leaves the plant, and it was thought that this requirement would correspond more closely with 24-hour B.O.D.s than those for a longer period. A careful check on the relationship between the 2 and 5-day B.O.D.s indicated that the former was 0.42 of the latter instead of 0.31 as would be expected from Phelps formula.

Using this factor we find that the average weekday strength of the waste is 795 p.p.m. 5-day B.O.D. or a total of 3540 pounds per day. Allowing .17 pounds 5-day B.O.D. per capita per day, the total population equivalent of the brewery is 21,000 or about 14 persons per 31-gallon barrel of beer. For each barrel of beer there was approximately 350 gallons of waste containing 1.1 pounds of suspended solids. These losses are in about the same range as those reported by Mohlman.[1]

Degree of Treatment Necessary

An ordinance of the City of Houston requires that wastes dumped into the bayous "shall be free from matter that will settle in the bottom of the channel, from all floating matter, and from any matter that can putrefy and cause offensive odors," providing as a test for meeting the last requirement that the waste shall have a methylene blue stability of 40 hours at 37° C. To meet this standard would require a very high degree of treatment for the strong wastes involved, estimated as high as 98 per cent; which is of course not practical. However the city agreed to consider the wastes from the Hughes industries as a unit, and this standard was met with the pilot plant effluent when the plant was operating at or below the rates finally adopted for the design.

Chemical Treatment

Chemical treatment of the wastes was given serious consideration. Spent lime was available from acetylene generators and steel turnings for ferric salts generators. Lower first cost, conservation of land, and freedom from possible odors also recommended this type of treatment. However, after extensive laboratory tests, using flocculation, chemical treatment was abandoned for the following reasons:

(1) The degree of treatment was not satisfactory. The B.O.D. of the wastes could be reduced only between 55 and 75 per cent.

(2) The results obtained were erratic—probably due to the varying nature of the wastes.

(3) A large volume of sludge was produced.

(4) This sludge filtered very slowly on a vacuum filter, and no chemical treatment was found which would make more than a slight improvement on the filtering rate.

The above tests were made with a small model flocculator and settling tank set up at the outfall of the brewery. The tests were run over periods of about 5 hours each, except the last two, which were for 2½ hours each. Flocculation was for 15 minutes and settling one hour. Samples taken every 15 minutes.

TABLE II.—*Results of Chemical Treatment*

Date 1937	pH		Chemicals Added, lbs./1000 gals.			1-day B.O.D., P.p.m.		Sludge	
	Inf.	Eff.	$Fe_2(SO_4)_3$	$Al_2(SO_4)_3$	$Ca(OH)_2$	Inf.	Eff.	Per Cent Solids	Per Cent Volatile
8/2	8.1	5.7	3.6	—	—	435	90	0.58	56
8/3	8.4	6.2	—	3.3	—	—	—	1.05	54
8/5	8.2	8.9	3.4	—	3.2	670	105	1.17	66
8/9	8.4	9.3	—	2.4	2.7	473	219	2.93	53
8/13	7.7	10.6	—	—	4.7	647	211	—	—
8/13	8.1	10.1	4.0	—	4.1	387	176	—	—

It required between 16 and 33 minutes to filter 500 c.c. of sludge with a 9.5 cm. Buchner funnel between the start and the time that the cake cracked. Various combinations of lime and ferric chloride were used with little effect in the filtering rates.

PILOT PLANT—TRICKLING FILTER

A pilot plant was built near the outfall of the brewery sewer and except for a short shutdown at Christmas was operated continuously from Nov. 16, 1937, to April 2, 1938 (Fig. 1). An operator was in constant attendance throughout the 24 hours. Hand samples were taken

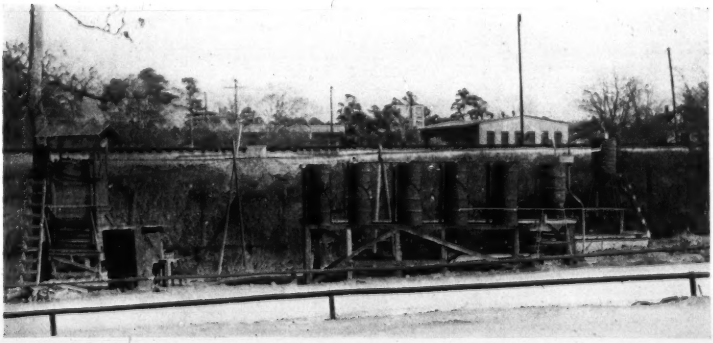


FIG. 1.—Brewery wastes pilot plant. From right to left: primary tank for trickling filters, primary tank, three aeration tanks and final settling tank for Hays Process, trickling filters. Filter secondary tanks are behind the filters.

every half-hour and composited, and the amount of wastes from the brewery flowing over a weir was recorded every fifteen minutes.

The trickling filter unit consisted of a preliminary settling tank, two filters, each 24 in. square and 6 ft. deep, and two final settling tanks. The settling tanks were made of 50-gallon oil drums with the bottoms removed and conical bottoms welded on. Each filter was dosed by means of a tipping bucket and a perforated plate for distributing the flow over the surface of the filter. The capacity of the tipping buckets was frequently checked and a counter on each bucket served as an accurate means of measuring the flow. Filter 1 was filled with stone

TABLE III.—*Trickling Filters in Parallel—Weekly Average Results*

Date 1937–8	Primary Settling Tank				Trickling Filters						
	24 Hr. B.O.D.		Suspended Solids			24 Hr. B.O.D.		Suspended Solids		Loadings	
	Inf., P.p.m.	Eff., P.p.m.	Inf., P.p.m.	Eff., P.p.m.	Filter No.	Eff., P.p.m.	Total Red., Per Cent	Eff., P.p.m.	Total Red., Per Cent	Gals. Acre/ Day	Lb. B.O.D./ 1000 Cu.Ft./ Day
12-13 to 12-18	465	439	304	432	1	283	39.0	120	72.3	3.01	42.1
					2	296	36.3	120	72.3	2.46	34.4
12-19 to 12-25	272	309	217	252	1	219	19.4	84	61.3	2.48	24.4
					2	172	36.8	78	63.0	2.34	23.0
12-26 to 1-1	298	320	300	428	1	198	33.5	108	64.0	2.06	21.0
					2	202	32.3	86	71.4	1.86	18.9
1-2 to 1-8	268	250	256	143	1	101	62.3	54	78.9	2.39	19.1
					2	103	61.5	65	74.6	2.14	17.0
1-9 to 1-15	286	239	423	266	1	44	84.6	60	85.8	2.54	19.0
					2	35	87.8	72	83.0	2.35	17.6
1-16 to 1-22	443	425	357	432	1	223	49.6	133	62.7	2.42	32.4
					2	167	62.3	89	74.4	2.12	28.8
1-23 to 1-26	403	256	123	183	1	118	70.8	72	41.5	2.27	18.5
					2	79	80.4	46	62.6	1.81	14.8

between 2 in. and 3 in. in size and Filter 2 with stone between 1 in. and 2 in. in size.

Operating Results—Trickling Filter.—From Nov. 16 to Dec. 8, 1937, the two filters were operated in parallel at the high rate of 6 million gallons per acre per day. As practically no reduction of the B.O.D. was obtained, the rate was dropped to 2 million gallons per acre. The weekly average results of operation at this rate are given in Table III. There was little difference in results between the two filters with the different size of stone when the loadings were the same. The results of operation are plotted in Fig. 1.

From Jan. 27 to April 2, 1938, the two filters were operated in series, with settling between the two stages. The weekly average results are given in Table IV and are plotted for comparison with the results of the

TABLE IV.—*Trickling Filters in Series—Weekly Average Results*

Date 1938	Primary Settling Tank				Trickling Filters					
	24 Hr. B.O.D.		Susp. Solids		24 Hr. B.O.D.		Susp. Solids		Loadings	
	Inf., P.p.m.	Eff., P.p.m.	Inf., P.p.m.	Eff., P.p.m.	Eff., P.p.m.	Total Red., Per Cent	Eff., P.p.m.	Total Red., Per Cent	Gals. Acre/ Day	Lb. B.O.D./ 1000 Cu.Ft./ Day
1-30 to 2-5 ...	748	281	299	248	63	91.5	61	79.6	3.60	16.0
2-6 to 2-12...	442	324	501	222	34	92.3	60	88.0	3.00	15.4
2-13 to 2-19...	341	244	295	191	17	94.9	84	71.6	3.15	12.3
2-20 to 2-26...	246	319	245	241	97	60.6	63	74.3	3.29	16.6
2-27 to 3-5 ...	379	347	293	247	199	47.5	77	73.7	6.38	35.1
3-6 to 3-12...	534	350	473	245	138	74.1	112	76.3	6.12	34.0
3-13 to 3-19...	307	314	373	227	27	91.4	79	78.8	5.12	25.5
3-20 to 3-26...	471	414	322	276	42	90.7	80	75.2	3.47	22.5
3-27 to 4-2 ...	448	358	372	195	23	94.9	67	82.0	2.41	13.6

parallel operation, in Fig. 2. It will be seen that the series operation of the filters gave much better results with the same B.O.D. loadings than did the parallel operation. The difference is more marked at the lower rates of loadings.

In speculating as to why the results with the series operation were better than could be obtained from a single filter, it is useful to con-

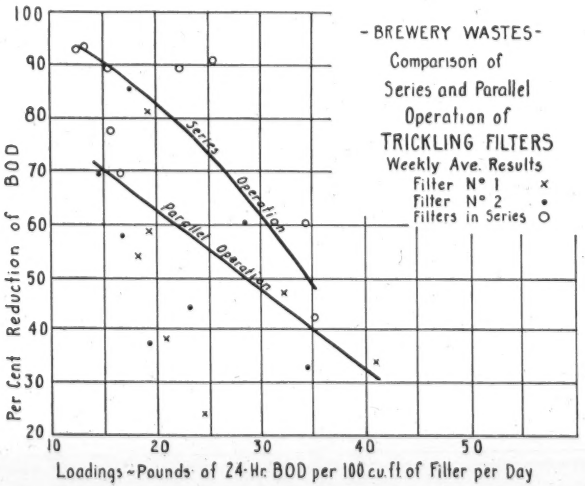


FIG. 2.

sider the first and second stage filters as equivalent to the upper and lower half of the single stage filter, respectively, and to make a comparison of the conditions existing with the two methods of operation. From this point of view the two-stage process would appear to have the following advantages which may have contributed to the better results.

(1) *Better Aeration.*—Probably more air was drawn into the filters at the higher rates of dosage. For the same loading per cubic foot of filter medium, it is obvious that the two filters in series must be dosed at twice the rate in gallons per acre per day. There is also some aeration in the dosing process.

(2) *Longer Period of Contact.*—It seems probable that the wastes were in contact with the stone for a longer period in trickling through

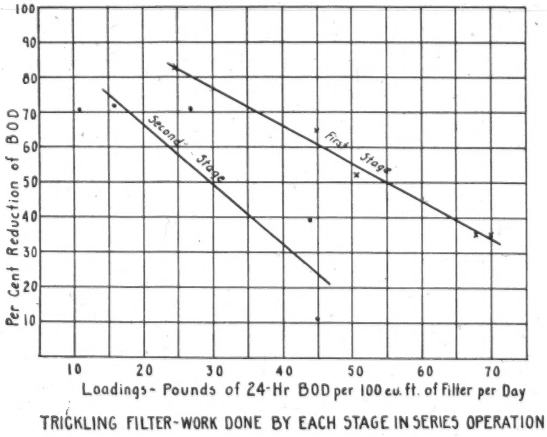


FIG. 3.

a total depth of stone of 12 ft. at a high rate than through 6 ft. at half the rate.

(3) *A Smoothing Out Effect.*—Levine, Nelson and Goresline [2] have shown that the quality of the effluent from a trickling filter varies markedly over the dosing cycle. With two filters in series the partly treated and easily oxidizable portion of the wastes from the first filter gets another chance in the second stage. The strength and character of the wastes vary almost from minute to minute. There should be a considerable smoothing out of these variations by the time the wastes reach the second filter and have passed through two wet wells, two settling tanks and the primary filter.

(4) *Removal of Solids.*—The removal of suspended solids brought down by the first stage may have made the remaining wastes easier to treat in the second stage.

For the last five weeks of the test B.O.D.s were made on the effluent from the first stage, thus making it possible to compare the work done by each stage. The results are plotted in Fig. 3. It will be seen that for the same loadings the first stage gives a greater reduction in the B.O.D. This is of course to be expected as in all methods of treatment the remaining organic matter becomes progressively more difficult to remove.

Table V gives the amount of sludge removed from the settling tanks and Table VI gives the suspended solids removals for the same period.

TABLE V.—*Amount of Sludge from Trickling Filter Pilot Plant*

Month	Gallons Treated	Gallons of Sludge Removed				Per Cent	
		Primary Tank	Secondary Tank	Final Tank	Total	Solids	Volatile
February	8,859	17	17	28	62	2.63	74.3
March	13,350	40	79	90	209	2.74	71.1
Total	22,209	57	96	108	271	—	—
Average	—	—	—	—	—	2.70	73.0

Per Million Gallons of Wastes

Gallons of Sludge	12,200
Pounds Dry Solids	2,750
Pounds Volatile Solids	2,000

TABLE VI.—*Suspended Solids Removed by Trickling Filter Pilot Plant*

Month	Suspended Solids, P.p.m.						Susp. Solids Removals	
	Influent		Effluent		Removed		Lb. per Mill. Gal.	
	Total	Vol.	Total	Vol.	Total	Vol.	Total	Vol.
February	333	252	66	53	267	199	2220	1660
March	410	328	78	54	332	274	2760	2260
Average	—	—	—	—	—	—	2560	2040

Results of a test on the digestion of the sludge, are given in Table VII and in Fig. 4. The sludge used for seeding was a well digested mixture of sludge from the brewery wastes which in turn had been seeded with digested sludge from the lagoons of the Houston activated sludge plant. The bottles were stored in the laboratory at room temperature, which averaged about 70° F. The drop in the gas production between the fourth and the eighth days was due to a period of cool weather when the laboratory temperature was low at night.

It will be seen that the sludge digestion was almost completed in 20 days. The digested sludge had the odor and appearance of that ob-

tained from domestic sewage. The nitrogen content of the sludge was high, between 7 and 8 per cent for the raw sludge and 3.6 per cent for the digested sludge.

Other Processes

In connection with the trickling filter pilot plant a pilot plant was also built to test out a contact aeration process, called the Hays process.

Table VII.—*Trickling Filter Sludge—Digestion at Laboratory Temperature*

Sample	Amount, c.c.	Per Cent Solids		Wt. of Solids, Gm.		
		Total	Vol./Total	Total	Vol.	Fixed
		Start				
Combined*	450	2.90	65.2	13.06	8.53	4.53
Blank	300	3.12	60.3	9.37	5.65	3.72
Raw	150	2.46	78.0	3.69	2.88	0.81
		Finish (32 Days Later)				
Combined	450	2.01	56.6	9.05	5.11	3.94
Blank	300	2.41	53.5	7.24	3.87	3.37
Raw†	150	—	68.5	1.81	1.24	0.57
		Weight Lost				
Combined	—	—	—	4.01	3.42	0.59
Blank	—	—	—	2.13	1.78	0.35
Raw†	—	—	—	1.88	1.64	0.24

	Per Cent Solids Digested		Gas Produced, 32 Days‡		
				Per Unit Vol. Solids Digested	
	Total	Vol.	Total, Liters	Liters per Gm.	Cu.Ft. per Lb.
Combined	30.7	40.1	1.920	0.56	9.0
Blank	22.7	31.5	0.360	0.20	3.2
Raw†	51.0	56.9	1.560	0.95	15.2

* By addition.

† By difference.

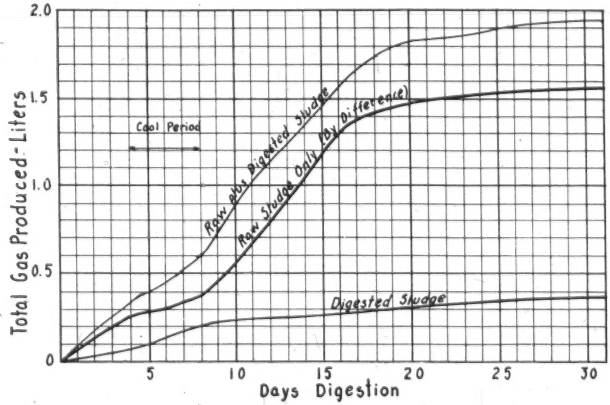
‡ 20-day gas production equals 94 per cent of 32-day gas production.

The plant consisted of a primary settling tank, waste from a 55-gallon steel oil drum, and four aeration tanks and a final settling tank, each made from one and one-half drums. The aeration tanks had hopper bottoms with wooden grids, and were filled with gravel from 3 to 4 in. in size. Below the wooden grids were perforated pipes for the diffusion of the compressed air. The plant was in operation from Jan. 14 to April 1, 1938.

The suspended solids removals were good with this process, although not quite so good as with the trickling filter, but the B.O.D. reductions

were low and very erratic. As a consequence it was decided that the process could not be made to obtain the degree of purification necessary for this type of waste without a considerable period of development, and it was abandoned because of lack of time.

Chlorination.—The results of a series of tests indicated that the 10-minute chlorine demand of the settled wastes was about 45 p.p.m. and that of the effluent from the trickling filter was 5 p.p.m. Since the total wastes amount to only 0.6 M.G.D. and the entire dry weather flow of the bayou above the junction with Bray's Bayou is only 2.2 M.G.D., the chlorination of the entire flow of the bayou for odor control in the summer months, if necessary, will not require an excessive amount of chlorine.



DIGESTION OF SLUDGE FROM BREWERY WASTES

FIG. 4.

TREATMENT PLANT

On the basis of the above results a treatment plant was designed and built (Fig. 5) the plant consists of the following units:

Pumping Station.—Two two-speed wet well type pumps, each in its separate wet well. Capacities each, low speed 600 g.p.m., high speed 1200 g.p.m. Float control.

Primary and Secondary Tanks.—Twin unit rectangular tanks each 12 ft. by 42 ft. by 9 ft. water depth. Detention period 1.5 hours at 0.6 M.G.D. Twin dosing tanks built on the ends of the settling tanks.

Trickling Filters.—Two circular filters each 100 ft. in diameter by 6.5 ft. deep, with rotary distributors. Stone (gravel) 1 to 2 in. in diameter. Loading during summer months at the maximum rate of brewery operation, 12.8 lb. 24-hour B.O.D. per 1,000 cu. ft. of filter stone per 24 hours.

Final Settling Tank.—Rectangular, 17 ft. by 50 ft. by 7 ft. water depth. Rate, 650 gallons per sq. ft. per day at 0.6 M.G.D.

Sludge Digestion Tank.—Circular, 32 ft. in diameter by 18 ft. deep. No provision for insulation or heating. Design based on a 30-day detention period during the summer months increasing to two or three times this period during the winter when the rate of operation of the brewery is low. Rating in pounds of sludge per cu. ft. of tank capacity per month, summer months, 3.4, yearly average, 2.3.

Sludge Drying Beds.—Area, 5,080 sq. ft. Assumed 16.5 dryings per year.

Space was left for a chlorinator if it becomes necessary for odor control or for sterilizing the water in the bayou.

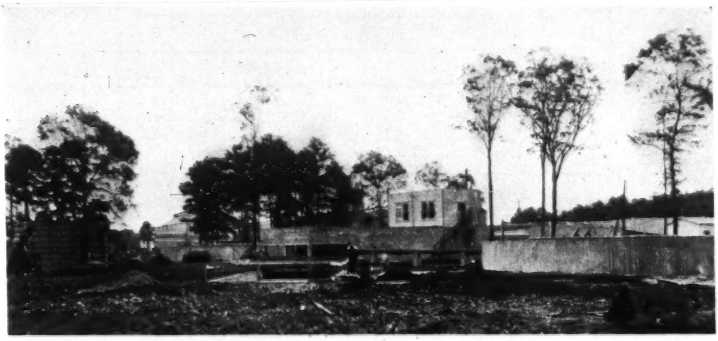


FIG. 5. Brewery wastes treatment plant nearing completion. In the middle are the primary and secondary settling tanks with dosing tanks on the end. In the front center is the final settling tank. At the extreme right and the left center are the two trickling filters. At the extreme left is the digestion tank with concrete still in the framework. The office and laboratory building is on top of the settling tanks.

The entire plant was designed for extreme flexibility in operation. Either pump can be used as the primary or secondary unit and either filter as the primary or secondary unit. The filters can be operated in parallel or series and recirculation of the wastes is possible for either or both stages up to the capacity of the pumps.

Automatic samplers were installed for the plant influent and effluent, the latter being designed to proportion the amount of sample to the flow. A recording flow meter was installed on the plant effluent. Laboratory facilities were provided for B.O.D. and solids determinations.

Because of the mild climate no buildings were provided over the main pumps and the sludge pump, although it may be desirable to do this at a later date.

The plant was built for the Gulf Brewery by the construction force of the Hughes Tool Company.

Acknowledgment

The entire project was under the supervision of Louis Godbold, the Plant Engineer of the Hughes Tool Company, with the writer as Consulting Engineer. H. W. Fletcher is Chief Engineer, and Col. R. C. Kuldell is President and General Manager of the Hughes Tool Company. F. H. Roberts is President and General Manager of the Gulf Brewery Company. We are indebted to Mr. Samuel Tolman, formerly of the Jeffrey Manufacturing Company, and now Engineer in Charge of the Wards Island Plant, who suggested the line of attack and did much to develop the process finally used. Helpful co-operation was received from the City of Houston Engineering Departmant, particularly from Mr. Wm. Pralle and Mr. W. E. White and from Mr. P. J. Alvin Zeller, Research Associate of the Texas Experimental Station.

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Operators' Reports and Suggestions

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LABORATORY STIRRERS

Recently the editor of this section of *The Journal* wished to study the possibilities of chemical coagulation in conjunction with, or in place of, the pre-aeration treatment at Decatur, Ill., which process has been discontinued for the past two years because the sprinkling filters were able to carry the load without the additional cost. The pre-aeration plant therefore stands in readiness for future growth of the city or the industries therein. Therefore chemical flocculation tests for Decatur sewage were only for future use and for temporary studies.

The cost of a six-jar stirrer was quoted at $120 to $150, and although such a stirrer would be very nice for large chemical treatment plants, the expense was out of all proportion to the amount of use to which I expected to put it. It was soon found that a real need exists for stirrers in small plants or by plant superintendents who wish to experiment with chemical treatment for a few months and then put the stirring device in the attic or dismantle it entirely (or perhaps, after proving the value of the flocculator or stirrer to purchase one of the more expensive commercially manufactured apparatus).

A little investigation showed a number of types of such stirrers, each possessing certain advantages. Five of these are presented below with a few descriptive remarks so that anyone wishing to build a similar device could use these as a basis.

In Fig. 1 is shown the Chicago Flocculator presented by E. Hurwitz. This might be called the individualized stirrer, in that each stirrer is independent and may be operated or not, while the others are in operation, by plugging the individual motor stirrers into the line as shown in the drawing. The chief advantage of this stirrer is that it can be made up from ½ inch pipe and fittings as shown, each stirring device being a universal motor-reduction gear unit (Speedway Universal Motor-gear No 911W). The speed of all the units is controlled by a single rheostat in the power line. The cost estimate for a six-jar stirrer is given by Hurwitz as follows:

6 Universal Motor-gear units (lots of 6 @ 5.55)	$33.25
1 switch	.20
6 outlet plugs	1.20
1 rheostat 400 ohms (any radio store)	.25
½ in. galv. pipe-fittings @ 10¢	2.00
½ in. galv. pipe, 25 ft. @ 15¢	3.75
Paddles from scrap iron	no charge
6 battery jars @ 60¢	3.60
Total 6-jar stirrer	$44.25

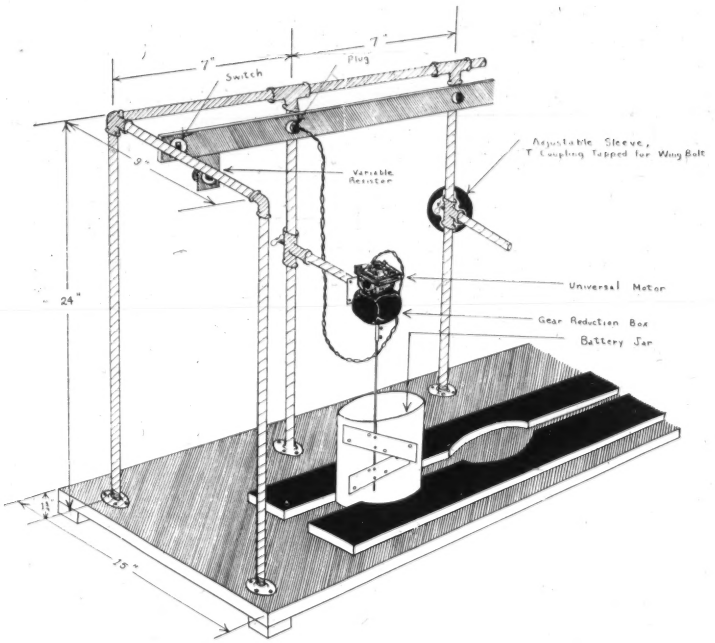


FIG. 1.—The Chicago Stirrer.

This stirrer is easy to make and the major cost exists in the number of motors necessary. I am inclined to think most people may find they have to pay some where around $3.00 for a rheostat of sufficient capacity to control the 6 motors.

The stirrer shown in Fig. 2 is one designed by L. A. Nalefski, Supt. Filtration, Water Department, Decatur, Illinois. In this apparatus the six stirrers are operated by one of the little universal wound motor-gear units (No. 911W, Speedway Mfg. Co., Cicero, Illinois) described above, through a drive shaft and bevel gears. The whole drive mechanism consisting of motor, drive shaft, gears and paddles are supported on a 3-inch channel iron "A" which is suspended through pulleys "B," wire rope and window weights, so that it may be easily raised out of or lowered into the six battery jars of test liquid. The speed of rotation is controlled between 10 and 80 r.p.m. by a 300 ohm rheostat. The window weights rise and lower inside of 2-inch pipe "C" which support the mechanism and attach it to the laboratory bench. The drive shaft and gears require careful alignment and should be built in a machine shop. The cost will run from $50 to $60, unless you have your own machine shop as part of the plant.

FIG. 2.—The Nalefski Stirrer.

An easily constructed stirring apparatus is shown in Fig. 3 by A. L. Elder and G. W. Stahl, of the Department of Chemistry of Syracuse University. The cost should not be more than $15.00 exclusive of the motor and labor.

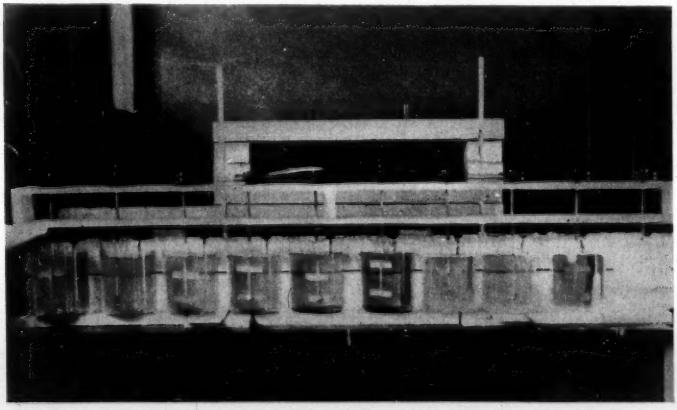


FIG. 3.—The Elder-Stahl Stirrer.

The materials necessary for a 10-beaker set are 21 small steel wheels, 2 in. in diameter; ten steel rods, 10 in. by ⅛ in., such as are found in Gilbert and Erector sets or may be obtained from the manufacturers; one or two cone reduction pulleys, 6 in. in diameter, with axles to fit; two ring stands; two iron clamps with flat arms such as are used on filter funnel racks; ten cork borers, ⅛ in. in diameter; 9 ft. of lath lumber ⅜ in. by 3 in., and 10 ft. of heavy lumber 2 in. by 6 in. to be used as a motor support as well as a support for the reduction pulleys, and a motor fitted with a reducing gear. On each of the stirring rods are soldered two tin plates, 1½ in. by ½ in. The lower half of the

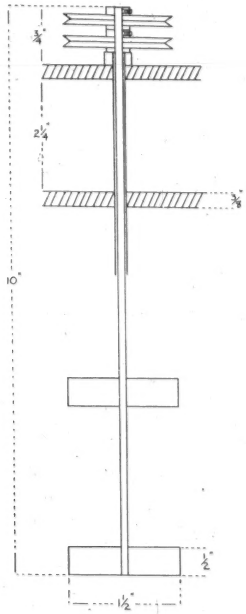


Fig. 4.—Stirrer.

stirring rods may be enameled to provide an easily cleanable surface and prevent corrosion.

Fig. 4 shows the arrangement whereby the cork borers serve as a satisfactory sleeve for the free revolution of the stirrers, which may be lubricated with vaseline. The stirring rods are spaced 5 in. apart on the rack and the center rod holds three of the small wheels, one of which is attached to the reduction pulley by means of a light rubber belt. The motor is connected to the reduction pulleys by a continuous leather belt. The stirring rod wheels are connected by means of a continuous tight string belt in a figure eight formation. A little talc serves to keep

the belts from slipping. They should be loosened while the apparatus is not in use.

A white backboard with horizontal and vertical black stripes serves as an aid in estimating rates of sedimentation. It is suggested that during sedimentation the stirrers be removed from the solutions by raising the stirring rack on the two ring stands.

The finger-tip ease with which the Nalefski stirrer (Fig. 2) is raised and lowered for filling and refilling the battery jars, and the use of one small motor-gear unit for the drive appealed to me as a very desirable feature. Dr. Elder's stirrer (Fig. 3) solved the costly drive mechanism of Nalefski's apparatus. I have combined the two types in what may be called the Decatur Stirrer as shown in Fig. 5. The drive

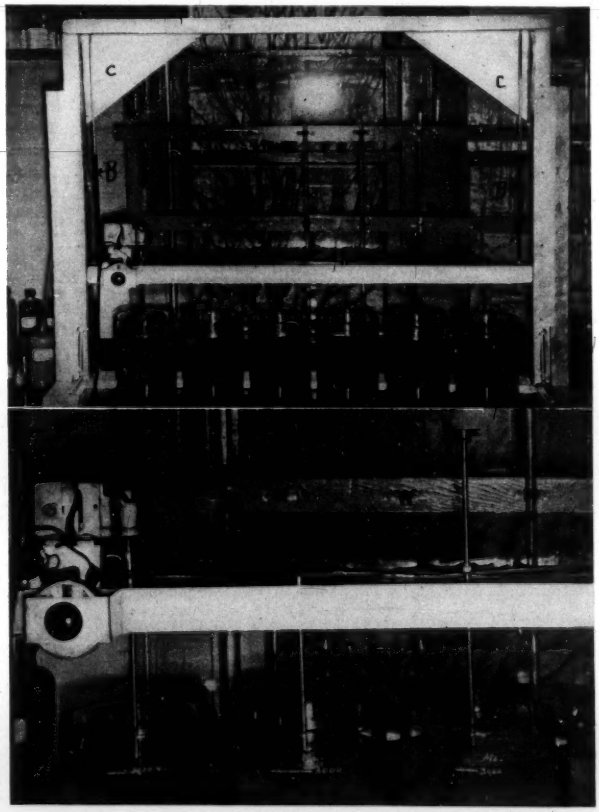


FIG. 5.—The Decatur Stirrer.

mechanism is the universal motor-gear unit (described above) which operates the stirrers by a 3/16 inch round leather belt which passes in a figure eight fashion over a single set of 1½ inch brass pulleys. The stirring shafts rest on and pass through small thrust ball bearings "A" to reduce friction. These ball bearings rest in counter sunk holes in the 2 by 4 support. The stirring rods and paddles are of brass because we had the material on hand; iron would be better, stainless steel best. The entire supporting mechanism is made from good quality 2 by 4 inch lumber. The lifting mechanism must be securely guided "B" so that it will raise and lower without binding (note *A* in Fig. 5) and the 2 by 4 upright supports should be braced at the top "C" to strengthen the support and prevent side sway. Sheet metal cases were made to surround the lead weights so that in case of accidental fall the table or apparatus nearby would not be damaged.

The cost of this apparatus is summarized as follows:

1 Speedway Universal Motor-gear No. 911W	$ 6.00
1 300 ohm rheostat (Ohmite Co.)	3.00
6 ¼ by 15/16 by 25/64 in. thrust ball bearings	2.14 B
6 ¼ by 1½ in. brass pulleys (G1217)	2.52 B
6 ft. round leather pulley belt, 3/16 in.	.40 B
Misc. ¼ in. shaft coupings	.34 B
1 pc. ¼ in. brass rod 12 ft. long @ 4.6¢	.55
Misc. screws and nuts	.50
1 2 by 4, 18 ft. long for frame	.50
6 battery Jars @ 60¢	3.60
Total material	$19.70

The apparatus is reasonably light and can be moved from one table to another or into the store room when not in use. The $3.00 rheostat is one we had for another purpose and is perhaps more expensive than necessary (see Hurwitz above). The items marked B in the cost summary were purchased from the Boston Gear Works, Inc.

The stirring apparatus designed at the Waukegan, Illinois, sewage treatment plant, is a modification of the one described by Rudolfs and Gehm in *This Journal*, **8**, 196 (1936). A photograph of the Waukegan apparatus is shown in Fig. 6.

The apparatus was built up from a welded angle iron frame; part of this frame being given to us by our mechanic. The frame is 60½ in. long, 50¾ in. high and 12¼ in. deep. The glass jars used are cylindrical of 2½ gallon capacity. The motor is a ¼ h.p. G. E. motor which was purchased second hand at a cost of $15.00. A 4-in. sheave is attached to the motor which connects, by means of a V-belt, to a 6-in. sheave on the speed reducer. The sheaves and belt cost a total of $4.00. The speed reducer has a ratio of 48 to 1 and cost about $12.00. A four-step cone pulley is attached to the speed reducer and another to the line shaft above; which shaft is supported by four bronze pillow blocks. The pulleys are driven by a quarter-inch round leather belt. To facilitate changing the belt from one pulley to another a brass idler

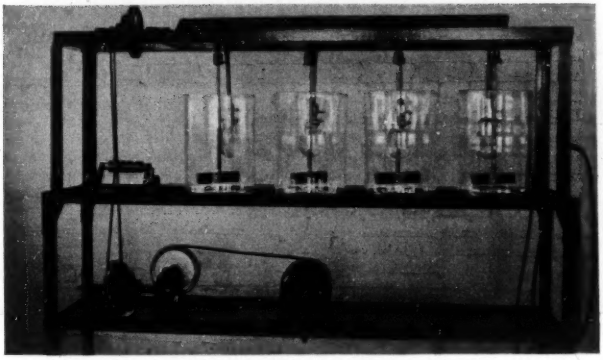


FIG. 6.—Waukegan Stirrer.

was constructed. The drive is transmitted to the vertical paddle shafts by bevel gears. A metal guard covers the line shaft and gears. The paddles may be operated at 115, 68, 25 or 10 r.p.m. The paddles are of brass and the shafts are removed by means of a thumb screw. In this way any combination of paddles may be operated. Electric lights (40-watt bulbs) having a reflector in the back of them, have been attached to the frame so as to have one light behind each jar. A control switch on the frame makes it possible to start the motor without interfering with the lights. Each light may also be turned on or off as desired. The total cost of the apparatus was approximately $90.00, exclusive of labor. Most of the fittings were machined by our mechanic and the entire apparatus was assembled by him.

Perhaps there are other designs which have special advantages that are cheap and easy to build. If you have one why not send it in to me. Getting gadgets by voluntary contribution from your operators is like pulling teeth or quieting a foaming digestion tank. Loosen up, send in gadgets, your annual reports, etc., and keep this section from being a one man or localized affair.

EXCERPT FROM REPORT ON THE DANBURY, CONNECTICUT, SEWAGE TREATMENT PLANT FOR THE YEAR ENDING JUNE 30, 1938

BY WALTER E. KUNSCH

Superintendent

When, on April 19, 1937, the trickling filters were put into permanent use, there was brought to a conclusion a long and expensive program of construction, designed to give the wastes of Danbury complete treatment to such an extent that they would cause no further nuisance in the

receiving stream. The plant was designed for a flow of 6 M.G.D. but can treat 8 M.G.D. for short periods.

Sewage flows for this year were consistently higher than those for the previous year and showed an average of 5.2 M.G.D., The sewage coming to the plant was given complete treatment throughout the year with the exception of a short period in September when it was bypassed in order to permit the installation of two 30-in. Everdur gates at the influent manhole.

Results of operation given in the table below show the average of tests taken by the Connecticut State Health Department.

	Turbidity		Suspended Solids		B.O.D.	
	P.P.M.	Per Ct. Removal	P.P.M.	Per Ct. Removal	P.P.M.	Per Ct. Removal
Raw Sewage	435		205		278	
Primary Tank Effl.	156	63.9	71	65.4	150	46.0
Trickl. Filter Effl.	52	88.1	58	71.7	47	83.1
Final Tank Effl.	36	91.9	34	83.5	35	87.5

Two of the state tests for biochemical oxygen demand were taken in July, 1937, when the trickling filters had not been in use long enough to come up to maximum efficiency. These two tests were averaged with the others and thus brought the year's average down. Since July, 1937, all B.O.D. tests have shown a removal of 90 per cent or better through the plant.

Of the relative stability tests taken on the plant effluent once weekly since Sept. 20, 1937, all have shown a stability of 99 per cent except three, which ranged from 90 to 97 per cent.

Maintenance

All maintenance problems and repairs were taken care of by the workers at the plant except in those cases where lack of proper tools or need of professional advice made outside help necessary.

Minor repairs to the automatic coarse screen included the replacement of short lengths of worn chain. The whole chain was wearing rapidly and it was evident that it would soon have to be completely renewed.

The fine screens continued to give good service and were comparatively trouble-free. The brush drive shaft on one screen was re-aligned in order to give better cleaning to the plates. The brushes do not show a great deal of wear and will probably run at least another year without replacement. Compared to experience at other screening plants, our brushes are giving abnormally long service. They are already completing their third year of use. In many plants it is necessary to replace them every year.

The pits underneath each fine screen were cleaned five times during the year and large amounts of grit removed. It is quite evident that the efficiency of grit removal in the present coarse screen and detritor is very low. Some of this grit finds its way to the settling tanks and digesters and causes rapid wear on the scrapers and other equipment in those tanks.

Settling tank maintenance is negligible. The channels are cleaned and the grease skimmed from the tanks once weekly. The superstructures of the tanks were given two coats of paint in the fall.

Digestion of sludge was satisfactory throughout the year. However during the latter part of the winter heat transfer from the hot water coils in the Dorr digester became noticeably poor, and from that time on the temperature of the tank dropped slowly instead of remaining at the desired 80 degrees F. This condition could be caused only by caking of sludge around the heating coils, thus forming an insulation against the transfer of heat, and it was realized that it would be necessary to empty the digester sometime before the next winter if the tank was to be kept warm and digesting properly.

Humus sludge from the recently completed final settling tanks and trickling filters almost doubled the amount of solids pumped to the digesters in previous years, and before sludge could be drawn to the drying beds in the spring, the sludge layer in the digesters was abnormally high. With the aid of warm, dry spring weather, 53 beds of sludge were drawn by the end of June, making a total for the year of 90 beds. The year's total of sludge drawn to the beds was 51,400 cu. ft. and for dried sludge removed from the beds, 25,500 cu. ft.

Late in spring it was realized that the available sludge bed area would not handle enough sludge to permit the emptying of the Dorr digester and it was decided to make alterations to a nearby slow sand filter and use it as a sludge bed. This improvement adds 9,000 sq. ft. to the previous sludge bed area and makes a total of 45,000 sq. ft. available. This area was subsequently found to be adequate to permit the emptying of the Dorr digester. The work done on this digester will be covered in the next report.

Chlorination for the 1937 summer season stopped on September 17. The 1938 season was started on May 21. One carload of fifteen tons of chlorine proved sufficient for one season's demands. An average dose of 220 lb. per day through the season eliminated all carrying odors at the trickling filters. It is doubtful whether any fly control was obtained. The chlorine proved valuable in eliminating fungus growths from the piping and also helped rid the beds of pooling.

When the trickling filters were first started in operation it was feared that fur which finds its way through the screens and settling tanks might in a comparatively short time clog the spaces between the trickling filter stones and thereby cause serious trouble. Consequently the sewage liquor was screened again at the distributing manhole by manually cleaned screens. These screens clogged only about three

times daily and after experimenting with ⅛ in. mesh screens, the latter were put into use in November, 1937. These screens remove a great deal more fur and other floating matter and are cleaned about ten times per day. It was found that the 800 ft. pipe line between the settling tanks and this manhole released enormous amounts of fungus growths when the sewage temperatures ranged from 50 to 55 degrees F. December and March appear to be the peak periods for release of this fungus. During these periods it is almost impossible to keep the ⅛ in. mesh screens clean and much of the fungus goes through to the trickling filter distributing arms. During these periods the distributors clog rapidly and must be cleaned almost daily in order to prevent their combined capacity from dropping below 6.0 M.G.D.

Thus far the fears about the fur on the trickling filters have proven groundless. Other than the trouble from fungus growths the distributors have operated very well, with only very minor operating difficulties appearing. Pooling on the surface of the filters was noticeable only in the late winter months. This pooling began to disappear with the warmer weather and the first few days of chlorination removed it entirely.

The trickling filter fly, *psychoda,* did not appear to any great extent in 1937, but the warm weather of early spring in 1938 brought them out in great numbers. Flooding of the filters for fly control was practised for the first time on May 5, 1938. Flooding was continued at weekly intervals and by the end of June the fly nuisance was much abated.

The winter of 1937–38 was comparatively mild but indicated that winter operation of the trickling filters would not give serious trouble. It was found that even a heavy fall of snow would be immediately melted away under the distributors. Ice on the stones appeared only in a few concentric circles near the center of the beds where the stones did not receive the direct stream of liquid but only the spray. Spray also froze at the outer edge of the bed but caused no trouble since the stone drops away at a 1½ to 1 slope at the point and leaves ample room for piling up of ice. Spray did give some trouble by freezing on the rods and braces of the distributor where it would, if allowed to become thick enough, weight down the rods to the breaking point. This possibility was overcome by knocking the ice off the rods every four hours during cold weather.

Results of trickling filter operation, as given in the first part of this report, have shown that this method provides ample secondary treatment for the wastes of the city.

The final settling tanks remove large amounts of solids from the trickling filter effluent. Whereas at most plants of this kind one or two pumpings per week are sufficient for sludge removal, we have found it necessary to pump daily from these tanks. The humus sludge has a moisture content of 94 per cent and increases the solids load on the digesters by almost one-half over the loadings previously obtained from the primary tanks alone.

Operation of the final tanks was twice interrupted for a period of one week by the filling of the sludge hoppers and clogging of the sludge pipes with stone dust, which washed through from the trickling filters. It is believed that this stone dust is the result of the washing action of the liquid passing over the trickling filter stones rather than the result of any breaking up of the stone due to frost or chemical action. Had the stone been sifted immediately before being put in place in the filters, this trouble would not have appeared.

The presence of this material also increases the difficulties of pumping the sludge to the digesters. The static head of 48 ft. against the pump plus the friction head caused by forcing the heavy sludge through 800 ft. of pipe to the digesters, causes a load which the Carter pump was not built to withstand. Only by running the pump at a very slow rate can the sludge be removed.

The Dorr plunger pump continues to give good service in the pumping of raw sludge. The Chicago centrifugal pump is used as a standby.

The old sand filters were used during periods of high flow to treat all liquids beyond the capacity of the tricking filters, and gave a good effluent. About nine acres of beds remain available for use. All beds were cleaned once during the year.

Major Improvements

Early in the year an important improvement was made at the influent manhole by replacing two heavy 30 in. shear gates, which were no longer water tight, with Everdur slide gates with wheel stands.

All overground gas piping leading from the digesters was provided with unions and cleanouts and was insulated against the weather.

The sludge beds were protected from ground and surface water by the installation of 150 ft. of tile in open ditch and 180 ft. of vitrified tile in an underground drain. A much needed regrading of sludge beds was begun in the spring of 1938 and by June 30, ten beds had been completed. The banks of the sludge beds were regraded for appearance and ease in mowing.

A small building, 11 by 16 ft. was erected for winter protection for the ⅛ in. mesh screens at the manhole which diverts the settled sewage to the four trickling filters.

Baffles were installed at the outlet end of the final settling tank.

In March, 1938, a W.P.A. project was started for the purpose of making improvements to the roads, drainage, and grounds at the plant. By the end of June, 1,000 feet of road had been built near the trickling filters, about two acres of ground graded, and drainage, provided for all land south of the trickling filters. It is hoped that with the W.P.A. aid it will be possible to rebuild all roads at the plant for permanence and regrade much of the grounds for better appearance and ease of maintenance.

General Information and Data

In the table below are given the important statistics on plant operation for the past year.

Sewage Flow	1,898,920,000 Gal.
Sewage Flow (per Day)	5,200,000 Gal.
Coarse Screenings Removed	8,500 Cu. Ft.
Fine Screenings Removed	53,278 Cu. Ft.
Raw Sludge Pumped	3,863,140 Gal.
Humus Sludge Pumped	1,008,745 Gal.
Dry Sludge Solids to Digesters	1,470,000 Lbs.
Digested Sludge to Drying Beds	51,420 Cu. Ft.
Dried Sludge Removed	25,550 Cu. Ft.
Gas Generated	4,875,100 Cu. Ft.
Light and Power Used	47,717 KWH.
Chlorine Used	24,330 Lbs.
Cost of Operation—Total	$24,986.26
Cost of Operation Per Mil. Gal.	$13.15

The plant serves a population of 21,000 people and also receives the industrial waste from about one-third of the local hat and fur factories. There are no sewage pumping stations as the flow to the plant is all by gravity. The present plant was designed for an average flow of 6 M.G.D. Normal treatment consists of coarse and fine screening, primary settling, digestion of solids and sludge drying on open beds, chlorination in summer, oxidation on trickling filters, and final settling of effluent. Nine acres of slow sand filters are available for flows over the capacity of the trickling filters. The cost of the plant excluding land and slow sand filters was about $400,000. The consulting engineers were Sanborn and Bogart of New York City.

Editorial

WATER POLLUTION IN THE UNITED STATES

Under this title the Special Advisory Committee on Water Pollution of the National Resources Committee has made a report of some 165 pages on pollution by sewage and industrial wastes in the United States. The report is the third on this subject. It was submitted to Dr. Abel Wolman, Chairman of the Water Resources Committee, on Dec. 20, 1938, and forwarded to President Roosevelt on Jan. 25, 1939, by Chairman Ickes of the National Resources Committee, with the recommendation that Federal legislation should provide for Federal financial and technical assistance in pollution abatement and that construction activities for which financial aid is given should be planned as an integral part of a general public works program.

The report was transmitted to Congress by the President on Feb. 15, 1939, with the following recommendations:

> It is my opinion that pending further experimentation with interstate and State enforcement activities, Federal participation in pollution abatement should take the general form of establishing a central technical agency to promote and co-ordinate education, research and enforcement. On the basis of recent experience, it should be supplemented by a system of Federal grants-in-aid and loans organized with due regard for the integrated use and control of water resources and for a balanced Federal program for public works of all types. The time is overdue for the Federal Government to take vigorous leadership along these lines.

The report is concerned mainly with estimated costs of a long-range program of treatment of sewage and industrial wastes, and with the administrative aspects of water pollution control.

The cost over a period of 10 or 20 years is estimated as follows:

	Millions of Dollars
Treatment of municipal sewage	1,000
Treatment of industrial wastes	900
Disposal of oil-field brine	100
Controlling mine-waste waters	52
	2,052

The report includes tables showing cost of treatment of sewage regionally, with some 440 millions allocated to the region from New England to the Delaware Basin. The industrial waste estimates are listed for various types of industries, based on unit costs for which, the report states, reliable statistics are available. The summarized costs are compiled from these unit costs adjusted for the volume of production indicated by the 1935 Census of Manufactures. The total of 694 millions obtained in this way is considered low, and is therefore raised to 800 millions minimum and 900 millions maximum.

Some of the detailed estimates are of interest. The larger items and totals of the various groups are shown below:

	Millions of Dollars	
Foods and Beverages		
Milk products	32.6	
Canneries	22.4	
Distilled liquor	10.4	
Malt beverages	41.0	
Meat packing	30.0	
Cereal preparation	30.0	
Beet sugar	7.6	
Total		205.4
Chemicals		28.3
Gas and Petroleum		35.0
Textiles		54.0
Ferrous Metals		
Coke-oven products	10.0	
Steel works	10.0	
Total		20.0

Non-Ferrous Metals	21.6
Paper	129.0
Rubber goods	1.0
Sub-total	494.3
Miscellaneous	100.0
Total added for contingencies	100.0
Grand total	694.3

In view of the 200 millions in miscellaneous and contingencies, a wide variation in any individual item would not affect the total to any extent. The rubber industry might have been spared its lone million.

The table gives a good perspective of the gross range of responsibility of various industries for pollution of water. Food and paper industries are the largest specific items. The large amount for malt beverages is of interest.

The following comment is made with reference to industrial wastes:

> Few manufacturers benefit directly from an improvement in the quality of waste discharged from their plants. Industrial waste treatment or recovery does not usually pay a net return. It must be regarded as a charge on the cost of production. Being non-revenue producing, proposed expenditures for that purpose meet little encouragement from the financial groups interested in the industry.

Loans to industry are recommended by the committee, at lower interest rates than those prevailing in the market for industrial funds, but grants are not considered necessary or desirable.

Administration of pollution abatement is reviewed, with special reference to interstate compacts and agreements, such as the New York-New Jersey Commission, the Ohio River Compact, the Potomac Basin Compact, the Delaware Basin Agreement, and the Tri-State Compact (Minnesota, North Dakota and South Dakota). The pollution abatement program in the Potomac Basin is estimated to cost $17,300,000.

With reference to Federal functions in pollution abatement, the report recommends that "Federal action should look to the improvement of State enforcement; research and education; the stimulation of interstate compacts and agreements; the promotion of integrated basin-wide plans; and financial aid in the form of loans and grants to meritorious projects."

The specific course suggested for carrying out the recommendations of the report is as follows:

(*a*) Applications for grants-in-aid and loans would be received by the U. S. Public Health Service providing (*sic*) they had been approved by the appropriate State Health authority.

(*b*) The Service would examine the applications and each year would prepare a list of projects for which grants-in-aid and loans during the ensuing fiscal year were recommended.

(*c*) The national co-ordinating and planning agency would advise on whether or not the projects were in harmony with comprehensive plans for water use and control.

(*d*) The list then would be submitted to the Bureau of the Budget for consideration in relation to public-works programs for other purposes. The President would transmit his recommendations for appropriations to the Congress as a part of the annual Budget.

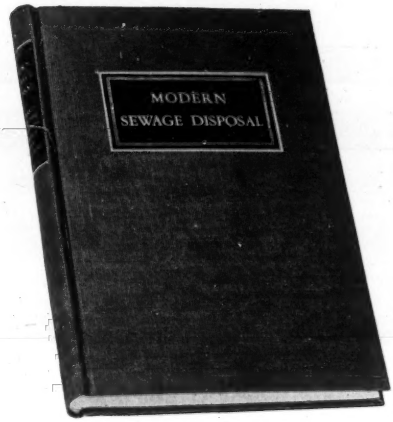
(*e*) The Congress would appropriate such sums as it deemed necessary and desirable to finance the recommended program.

(*f*) Grants-in-aid and loans from appropriated moneys for authorized projects then would be made by the public-work agency, which also would inspect the work during the construction period.

The remainder of the report includes an appendix summarizing state laws on pollution, also brief statements by Harry E. Jordan on costs of water filtration plants and by Dr. Willem Rudolfs on water pollution abatement in western European countries, a revision of a report by the U. S. Public Health Service. The report also contains some technical information on water standards for fish and aquatic animals, by Dr. M. M. Ellis, and rather general information on industrial wastes.

The report was referred to the Committee on Rivers and Harbors on Feb. 16, 1939, as House Document No. 155 and is under consideration by the 76th Congress now in session.

F. W. M.



This

Anniversary Volume . . .

is published to commemorate ten years of service by the Federation of Sewage Works Associations and is dedicated to the many operators of sewage works, research workers, engineers and public officials who have contributed to the development of the art of sewage treatment in the past.

The editor of MODERN SEWAGE DISPOSAL is Langdon Pearse, and the following is a list of the chapters and their respective authors:

C. A. EMERSON, JR.: The Federation and Its Relationship to Sewage Disposal.

C. G. HYDE: A Review of Progress in Sewage Treatment During the Past Fifty Years in the United States.

LANGDON PEARSE: Functional Outline of Processes of Sewage Treatment.

SAMUEL A. GREELEY: Sedimentation and Digestion in the United States.

KARL IMHOFF: Sedimentation and Digestion in Germany.

W. E. STANLEY: The Trickling Filter in Sewage Treatment.

F. W. MOHLMAN: Twenty-five Years of Activated Sludge.

W. DONALDSON: Chemical Treatment of Sewage.

LINN H. ENSLOW: Chlorine in Sewage Treatment Practice.

GEORGE B. GASCOIGNE: Mechanical Equipment in Modern Sewage Treatment.

MORRIS M. COHN: Utilization and Disposal of Sewage Sludge.

W. D. HATFIELD: The Works Laboratory.

C. A. HOLMQUIST AND C. C. AGAR: Bettering Sewage Plant Operation.

MAX LEVINE: Bacteriological Aspects of Sewage Treatment.

EARLE B. PHELPS: Bio-chemistry in Sewage Treatment.

W. C. PURDY: Limnological Aspects of Sewage Disposal.

N. T. VEATCH, JR.: The Use of Sewage Effluents in Agriculture.

H. W. STREETER: Disposal of Sewage in Inland Waterways.

A. K. WARREN AND A. M. RAWN: Disposal of Sewage into the Pacific Ocean.

A. D. WESTON: Disposal of Sewage into the Atlantic Ocean.

WILLEM RUDOLFS: Sewage Research.

HAROLD E. BABBITT: Research in Sewage Treatment at Educational Institutions in the United States.

C. E. KEEFER: Administration of Sewage Treatment Works.

GORDON M. FAIR: Mathematical Aspects of Sewage Research.

C.-E. A. WINSLOW: Pioneers of Sewage Disposal in New England.

ABEL WOLMAN: State and Other Governmental Functions in the Control and Abatement of Water Pollution in the United States.

H. T. CALVERT: Governmental and Local Functions in the Control of Sewage Disposal in Great Britain.

J. H. GARNER: Sewage Treatment in England.

E. J. HAMLIN AND H. WILSON: The Sewage Disposal Problem in South Africa.

H. J. N. H. KESSENER: Sewage Treatment in the Netherlands.

A. HEILMANN: Sewage Treatment in Germany.

L. F. WARRICK: The Prevalence of the Industrial Waste Problem

ROBERT SPURR WESTON: Treatment and Disposal of Industrial Wastes.

This 371-page reference manual has been priced so as to become available to the greatest numbers.

To Sewage Works Journal subscribers.....$2.50 per copy

To non-subscribers.....$3.50 per copy

(Foreign postage of 33 cents is extra)

FEDERATION OF SEWAGE WORKS ASSOCIATIONS

654 Madison Avenue **New York, N. Y.**

Proceedings of Local Associations

FEDERATION OF SEWAGE WORKS ASSOCIATIONS

MINUTES OF THE ANNUAL MEETING OF THE BOARD OF CONTROL

The Annual Meeting of the Federation of Sewage Works Associations was held at Leeds Restaurant, New York City, on January 20, 1939. Dinner preceded the meeting which was called to order by Chairman C. A. Emerson, Jr., who presided. Roll Call showed the following to be present in person:

Name	*Representing*
Charles C. Agar	New York State Sewage Works Association
H. G. Baity	North Carolina Sewage Works Association
A. C. Beyer	California Sewage Works Association
F. J. Biele	New York State Sewage Works Association
Wm. W. Buffum	Member-at-Large
W. W. DeBerard	Central States Sewage Works Association
E. F. Eldridge	Michigan Sewage Works Association
C. A. Emerson, Jr.	Pennsylvania Sewage Works Association
Linn H. Enslow	Member-at-Large
Gilbert R. Frith	Georgia Water and Sewage Association
F. Wellington Gilcreas	New England Sewage Works Association
Dana E. Kepner	Rocky Mountain Sewage Works Association
A. P. Miller	Federal Sewage Research Association
F. W. Mohlman	Editor
H. E. Moses	Pennsylvania Sewage Works Association
Wm. J. Orchard	Member-at-Large
Wm. M. Piatt	North Carolina Sewage Works Association
William Rudolfs	New Jersey Sewage Conference
G. S. Russell	Missouri Water and Sewerage Conference
L. W. Van Kleeck	New England Sewage Works Association
Earle L. Waterman	Iowa Wastes Disposal Association

Present in person, acting as proxy:

Name	*Representing*
A. S. Bedell (for F. W. Jones)	Ohio Sewage Works Conference
Gordon M. Fair (for W. C. Miller)	The Canadian Institute on Sewage and Sanitation
F. W. Mohlman (for H. R. Streeter)	Member-at-Large

The following were represented by proxy (name of proxy in brackets):

Name	*Representing*
Earnest Boyce	
(H. E. Moses)	Kansas Water and Sewage Works Association
A. D. Butler	
(H. E. Moses)	Pacific Northwest Sewage Works Association
H. J. Darcey	
(H. E. Moses)	Oklahoma Water and Sewage Conference
V. M. Ehlers	
(H. E. Moses)	Sewage Division, Texas Section, S. W. W. A.
P. S. Fox	
(Dana E. Kepner)	Rocky Mountain Sewage Works Association
John H. Garner	
(H. E. Moses)	The Institute of Sewage Purification
H. R. Hall	
(H. E. Moses)	Maryland-Delaware Water and Sewerage Assn.
M. D. Hollis	
(A. P. Miller)	Dakota Water and Sewage Works Conference
W. I. Leonard	
(H. E. Moses)	Pacific Northwest Sewage Works Association
Lewis Simonton	
(Gilbert R. Frith)	Georgia Water and Sewage Association
Richard C. Smith	
(H. E. Moses)	New Jersey Sewage Conference
W. W. Towne	
(H. E. Moses)	Dakota Water and Sewage Works Conference
Dario Travaini	
(H. E. Moses)	Arizona Sewage and Water Works Association
A. H. Wieters	
(Earle L. Waterman)	Iowa Wastes Disposal Association
Abel Wolman	
(H. E. Moses)	Maryland-Delaware Water and Sewerage Assn.
C. T. Wright	
(A. P. Miller)	Federal Sewage Research Association

Reading of the Minutes of the last Annual Meeting held January 21, 1938, was by common consent dispensed with since they had been published in the March, 1938, issue of SEWAGE WORKS JOURNAL.

Chairman Emerson made a brief verbal report, referring to the continued growth of the Federation during the past year. He spoke of the publication of the Nine Year Index in the September issue of the JOURNAL and of the Tenth Anniversary Volume, both creditable achievements. He anticipates further growth, but called attention to the serious problem of finances confronting the organization.

The Secretary-Treasurer next presented his report, briefly reciting the growth of the Federation in the ten years since its formal organization in Chicago on October 16, 1928, with seven affiliates, nine states represented, and only 411 members. Today there are 25 affiliates, 30 states being included and containing 80 per cent of the entire population of the United States. One affiliate each is in Canada and Argentina, with two in England. The close of the year showed a net membership of 2,472, an increase of 92 in 1938. The Secretary received $3,314.75 in dues, an increase of $216.25 over the preceding year, and forwarded the same to the Business Manager who received dues direct from several

of the affiliates. He reported that the Arizona and the Georgia groups had changed their names in 1938. No new affiliates were proposed.

The Secretary-Treasurer particularly called attention to the disturbing loss of old members, stating that in 1938 nearly 500 members did not renew membership, equivalent to nearly one-fifth of the year's net membership, urging that this loss should not be overlooked. On motion the report was accepted.

Business Manager Buffum then presented his report stating that the number of subscribers as of December 31, 1938, was 2,888 (2,681 in 1937), divided into members 2,489 and non-members 399. The cost of printing and mailing SEWAGE WORKS JOURNAL for the year 1938 totaled $8,877.23, or $3.07 per subscriber. Profit for 1938 amounted to $147.52 as compared with $1,633.13 in 1937, or approximated $1,500 less than last year's profit, about equal to the increased cost of the JOURNAL. Advertising income for 1938 was $6,130.11 as against $6,495.36 in 1937, a loss of $365.25. There were three pages less of advertising than last year.

Reporting on the Tenth Anniversary Volume, Mr. Buffum stated that 2,500 copies had been printed, with 1,000 copies bound. Some 4,000 letters are being sent to subscribers and former members, bringing the merits of the volume to their attention. He was of the opinion that the volume will pay for itself. Mr. Kepner inquired whether it would be practicable for each affiliate to have copies on hand at its meetings. Mr. Buffum stated this could be arranged. On motion the report was accepted.

Editor Mohlman made a brief verbal report on the JOURNAL, reaffirming his belief that the low subscription price made it available to small plant operators and others who would be unable to obtain it if it were more expensive. He hoped means would be found to continue at the present cost.

The Executive Committee and Publication Committee made no reports. Mr. Emerson reported that Chairman Streeter had informed him that the Membership Committee had some good prospects for new affiliates and hoped for expansion in that direction.

The report of the Finance Committee by Chairman Piatt evoked general discussion as to ways and means of increasing the Federation's income. Less advertising accounted for much of the reduction of profit over that of the preceding year. New advertising is needed as well as retention of old. The responsibility as also the opportunity of the Board members to assist in this field was emphasized. The unique value of SEWAGE WORKS JOURNAL was stressed as an advertising medium in both the national and international field where there is plenty of advertising now going elsewhere, of which the JOURNAL should receive its share. The Board members were strongly urged to give this matter serious consideration and each one was asked to help. It was moved, seconded and carried that the report be laid on the table temporarily.

Mr. Emerson next read the report of Langdon Pearse, Editor of the Tenth Anniversary Volume, set forth below, which report was by motion accepted with a vote of thanks to Mr. Pearse for his valiant work in taking charge of publication.

Dear Mr. Emerson:

As a matter of form, I am making herewith the final report on the Anniversary Volume, for presentation at the annual meeting of your Board. Following up the request of your Board that an Anniversary Volume be prepared to cover the field of sewage disposal, arrangements were made with prominent engineers and sanitarians in the United States, Great Britain, Germany, Holland and South Africa for the preparation of 32 articles covering a wide range of topics. As completed, the foreword of the Chairman of the Federation is followed by an introductory chapter of historical nature, then 18 chapters on topics in Sewage Treatment Practice, 4 chapters on Research, 7 chapters on Regional and National Aspects and 2 chapters on Industrial Wastes. The completed volume, containing 371 pages of text, is entitled "Modern Sewage Disposal." Printing began early in December. By the time this report is read, the books should be ready for distribution.

May I thank you at this time for the hearty co-operation you have given in the enterprise? To the authors, Dr. Mohlman and Miss Swope, may I extend my appreciation of their continued courtesy and co-operation which materially reduced the burden on the Editor. Needless to say, the counsel and aid of Mr. Buffum was very helpful, in assuming the responsibility of all business arrangements.

I hope that the volume will be of interest to a wide audience, not only the sewage works operators, but the general public, and that as such it will prove a fitting memorial of the Tenth Anniversary of the formation of the Federation of Sewage Works Association.

Yours very truly,
(Sgd.) LANGDON PEARSE.

The Chairman reported for F. W. Jones, Board representative on the Joint Committee for Revision of Standard Nomenclature for Sewage and Sewage Treatment, that he had received letters from Mr. Hansen and Mr. Greeley, representing A. P. H. A. and A. S. C. E., stating that they expected to be able to give early attention to this matter. A request of the Executive Committee, New York State Sewage Works Association, that the Federation proceed with a revision of standard sewerage nomenclature co-operatively with others, was received and ordered filed.

Article IV of the By-Laws of the Central States Sewage Works Association relative to affiliation with the Federation as changed was, on motion, duly approved.

The Board then proceeded to the election of officers for the ensuing year. Mr. Emerson reminded that he had circularized the Board members prior to the meeting explaining that both Mr. Buffum and himself were desirous of relinquishing their respective offices, having served continuously for ten years, and felt that others should undertake these tasks; that he had requested the Board members to give thought to this matter and to be prepared with suggestions, pointing out the serious difficulties involved because of limited income. General discussion followed and finally Mr. Orchard, after reviewing briefly the history of the growth of sewage treatment, in which he paid tribute to the outstand-

ing leaders in the field, moved the re-election of all those eligible of the present officers and committees. This, upon second, was carried. The nominations, upon motion, were closed and the Secretary instructed to cast a ballot. The following officers and committees were thereupon elected:

Officers

Chairman, C. A. Emerson, Jr., New York
Vice-Chairman, Linn H. Enslow, New York
Secretary-Treasurer, H. E. Moses, Harrisburg, Pa.
Business Manager, Wm. W. Buffum, New York
Editor, F. W. Mohlman, Chicago, Ill. (3 years)
(Term of Secretary-Treasurer expires in 1940)

Members-at-Large

Wm. W. Buffum, New York
Linn H. Enslow, New York
Charles G. Hyde, Berkeley, Cal.
Wm. J. Orchard, Newark, N. J.
H. W. Streeter, Cincinnati, Ohio

Executive Committee

C. A. Emerson, Jr., *Chairman*
Linn H. Enslow
H. E. Moses, *ex officio*
Wm. W. Buffum
Wm. J. Orchard

Constitutional Committees

Membership

H. W. Streeter, Federal, *Chairman*
A. E. Berry, Canada
F. Wellington Gilcreas, New England

Publication

A. P. Miller, Federal, *Chairman*
Wm. W. DeBerard, Central States
F. W. Mohlman, *ex officio*
Earle L. Waterman, Iowa

Special Committees

Research

William Rudolfs, New Jersey, *Chairman*

Finance

Wm. M. Piatt, North Carolina, *Chairman*
C. A. Emerson, Jr., New York
Dana E. Kepner, Rocky Mountain
C. D. McGuire, Ohio
F. W. Mohlman, Central States
Earle L. Waterman, Iowa

Joint Committee on Standard Nomenclature for Sewage and Sewage Treatment

Frank Woodbury Jones, Ohio

Mr. Enslow suggested that the Secretary send a review of the Board meeting to Presidents and Secretaries of affiliates as well as to Board members, and this was agreed to.

It was moved and seconded that the Chairman be authorized to appoint in ten days a committee of seven Board members to study and report by June 1, 1939, on ways and means to place the Federation on a sound financial basis. This was amended that the report should be circulated among the members of the Board. As amended, it was adopted.

After a rising vote of appreciation of the work of the officers and committees, the Board adjourned at 10:20 P.M.

Respectfully submitted,

H. E. Moses,
Secretary-Treasurer

REPORT OF SECRETARY-TREASURER, FEDERATION OF SEWAGE WORKS ASSOCIATIONS, FOR THE YEAR ENDING DECEMBER 31, 1938

With the close of this year the Federation has completed slightly more than ten years of existence. It was organized in Chicago on October 16, 1928, with seven affiliate Associations and a gross membership of 411. Pennsylvania was the farthest east, with New Jersey, New York and New England not yet organized. Five years later (1933), twelve more groups had joined, raising the total to nineteen. Since then six other Associations have affiliated, making a grand total of 25. There were no additions in 1938.

Thirty of the 48 states now have affiliates, nine states being represented in the original group ten years ago. These states contain nearly 80 per cent of the entire population of the United States. Canada has one group with more than 100 members, England two groups with a membership of 156, while in South America there is one affiliate in Argentina.

The close of this year shows a gross membership of 2,520; with a deduction of 48 dual memberships, leaving a net membership of 2,472, or a net increase of 92 in the past year. The membership details are shown below:

	Gross Mem's'p	Dual Mems.	Gross New Mems. and Reinstatem'ts	Did not Renew Sub. 1938	Membership	
					Incr.	Decr.
Arizona S. & W. W. Ass'n.	26	—	11	7	4	—
California S. Wks. Ass'n.	252	1	51	35	16	—
Cent. States S. Wks. Ass'n.	425	5	119	41	78	—
Dak. W. & Sew. Wks. Conf.:						
North Dakota	12	—	—	14	—	14
South Dakota	24	—	7	5	2	—
Federal S. Research Ass'n.	54	—	6	13	—	7
Ga. W. W. & Sew. Ass'n.	23	—	8	5	3	—
Iowa Wastes Disp. Ass'n.	44	1	18	11	7	—
Kansas W. & S. Wks. Ass'n.	27	—	5	10	—	5
Md.-Del. W. & S. Ass'n.	28	—	3	1	2	—
Michigan S. Wks. Ass'n.	97	—	20	24	—	4
Missouri W. & S. Conf.	29	1	21	29	—	8
New England S. Wks. Ass'n.	149	6	19	16	3	—
New Jersey Sew. Conf. Group	63	—	12	7	5	—
N. Y. State S. Wks. Ass'n.	537	19	134	66	68	—
N. Carolina S. Wks. Ass'n.	55	—	10	41	—	31
Ohio S. Wks. Conf. Group	107	1	19	12	7	—
Oklahoma W. & S. Conf.	—	—	—	1	—	1
Pacific N. W. S. Wks. Ass'n.	48	—	22	11	11	—
Pennsylvania S. Wks. Ass'n.	189	11	35	24	11	—
Rocky Mt. Sew. Wks. Ass'n.	29	1	5	4	1	—
San. Engr. Div. of the Arg. Society of Engrs.	1	—	—	23	—	23
Sew. Div.-Tex. Sec., S. W. W. A.	24	—	11	27	—	16
The Can. Inst. on Sew. & San.	121	2	44	5	39	—
The Inst. of Sew. Purif.-Eng.	105	—	16	16	—	—
The Inst'n of San. Engrs.-Eng.	51	—	4	12	—	8
	2520	48	600	460	257	117
	48				117	
	2472 Net Membership				140 Gr. Incr.	

There has been an increase in dues received by the Secretary-Treasurer and forwarded to the Business Manager over the preceding year of $216.25. The total received amounted to $3,314.75, distributed as appears in the table below. The petty cash account of the Secretary-Treasurer for stamps and miscellaneous office expenses amounted to $27.55.

Two affiliates have changed their names during the year, viz. Arizona Sewage Works Association to Arizona Sewage and Water Works Association; and Georgia Water Works and Sewage Operator's Association to Georgia Water and Sewage Association.

	For 1937	For 1938	For 1939	Total	Refund
Arizona S. & W. Wks. Ass'n.	(Paid dues direct to Mr. Buffum)				
California S. Wks. Ass'n.	$ 1.50	$ 378.00	$	$ 379.50	$ 6.00
Cent. States S. Wks. Ass'n.	1.50	636.75		638.25	
Dakota W. & Sew. Wks. Ass'n.		55.50		55.50	
Federal Sew. Research Ass'n.		79.50		79.50	
Ga. W. & Sew. Ass'n.	(Paid dues direct to Mr. Buffum)				
Iowa Wastes Disp. Ass'n.		61.50	25.50	87.00	
Kansas W. & S. Wks. Ass'n.		42.00		42.00	
Md.-Del. W. & S. Ass'n.		42.00		42.00	
Michigan S. Wks. Ass'n.	3.00	145.50		148.50	
Missouri W. & S. Conf.	(Paid dues direct to Mr. Buffum)				1.50
New England S. Wks. Ass'n.	4.50	217.00		221.50	4.50
New Jersey Sew. Conf. Gr.		84.50	1.50	96.00	
N. Y. State S. Wks. Ass'n.	16.50	775.50		792.00	3.00
N. Carolina S. Wks. Ass'n.		83.00		83.00	
Ohio S. Wks. Conf. Gr.		160.50		160.50	1.50
Oklahoma W. & S. Conf.			3.00	3.00	
Pacific N. W. S. Wks. Ass'n.	(Paid dues direct to Mr. Buffum)				
Pennsylvania S. Wks. Ass'n.	4.50	273.00		277.50	6.00
Rocky Mt. Sew. Wks. Ass'n.		36.00	13.50	49.50	1.50
San. Engr. Div. of the Arg. Society of Engrs.	(No 1938 subscriptions received from this group)				
Sew. Div.-Tex. Sec., S. W. W. A.		33.00	1.50	34.50	
The Can. Inst. on Sew. & San.		125.00		125.00	
The Inst. of Sew. Purif.—Eng.	(Paid dues direct to Mr. Buffum)				
The Inst'n of San. Engrs.—Eng.	(Paid dues direct to Mr. Buffum)				
	$31.50	$3238.25	$45.00	$3314.75	$24.00

As authorized by the Board at its last meeting, the Nine Year Index was published in the September issue of SEWAGE WORKS JOURNAL. This comprises both the subject and author index of Volumes I–IX of SEWAGE WORKS JOURNAL. This should be of great value to our members and subscribers.

The 10th Anniversary Volume, prepared under the able editorship of Langdon Pearse, is ready for distribution. Its appearance is awaited with interest, since it not only signalizes the Federation's Tenth Anniversary, but its text, prepared by 33 well-known engineers and sanitarians, is expected to cover a wide range of endeavor in the field of sewage and industrial waste disposal.

The record of the Federation for its first ten years is a creditable one. Its need has been demonstrated by its consistent growth—a six-fold increase in ten years. For the past two years it has been self-supporting. The excellence of the SEWAGE WORKS JOURNAL is everywhere admitted, its circulation extending into many foreign lands. In a number of states training of plant operators is provided by excellent Short Course Schools or by sectional group meetings. The yearly or sometimes oftener held meetings of the affiliates continue to attract the mem-

bers in increasing numbers and afford an excellent medium for the widening of knowledge in this field.

The past augurs well for the future. However, each Association should strive to retain its old members as well as to attract new ones. In 1938 nearly 500 members did not renew membership, equivalent to nearly one-fifth of last year's net membership. This seems too great a loss to overlook.

Further expansion may be found possible by way of new affiliates in those states not yet organized.

H. E. Moses,
Secretary-Treasurer

Reviews and Abstracts

H. W. STREETER

THE KESSENER BRUSH AERATION PROCESS

Results of Operation at Stockport Sewage Disposal Works

BY A. R. WARD

The Surveyor, **95**, 345–347 (Mar. 3, 1939)

Due to an increase in the estimated dry weather sewage flow at Stockport during the plant construction period (1922–1934), it became necessary to provide increased aeration. It was decided that the simplest solution was to recondition the sludge and adopt some form of preliminary treatment. In the original plant Haworth aeration units were used. After careful consideration of various methods of forced aeration, the Kessener brush type of unit was selected for the new extension to the plant.

In the two new units aeration is effected by ten rows of stainless steel combs. These combs are stamped from 26 S.W.G. chromium-nickel, stainless steel with a brinell hardness of 440. Overall diameter of combs, in position on the shafts, is 12⅞ in. Unit 1 can only be used exclusively for the reconditioning of the sludge. Unit 2 was designed for partial treatment, but provision was made to allow its use as a separate unit, so that its efficiency could be compared to the Haworth units.

From Jan. 21, 1938 to Mar. 10, 1938 (seven weeks) representing winter conditions, and from July 22 to Oct. 16 (12 weeks), Unit 2 was operated as a separate aeration unit. During these periods flow was 750,000 g.p.d. (at the rate of 900,000 g.p.d. in the day and 600,000 g.p.d. at night). Loading on the Haworth units was proportional. Power consumption per m.g. of sewage treated during Feb., 1938, was:

Haworth units	25.3	k.w.h. or 33.73 h.p.
Kessener units	16.79	k.w.h. or 23.39 h.p.

indicating a saving of 33.24 per cent in power consumption for the Kessener units.

Analytical results indicated rather better results from the Kessener units, as shown in the tabulation.

PER CENT PURIFICATION

	Ox. Absorbed from N/80 $KMnO_4$ in 4 Hrs. @ 80° F.	Suspended Solids	Albuminoid Nitrogen as Ammonia
Haworth Units	79.9	82.5	58.3
Kessener Units	81.5	88.9	58.3

Retention time in Haworth units was 14.5 hours, in the Kessener units was 7.48 hours. Sludge pumped for reconditioning was at the rate of 2.5 m.g.d. and the amount used in both units was the same—about 25 per cent by volume after one hour's standing, and equal to approximately 2.5 grams per liter.

During Aug., 1938, flow was controlled as for Feb., but in Sept. and up to Oct. 16, volume treated was in proportion to the flow. Sewage treated was weaker in the summer months. Power savings and analytical results for these later periods are quite comparable to the results quoted for February, 1938. The author's experience is that

the maximum quantity of sludge should be used that can be kept in reasonably good condition, this in turn necessitates a larger volume of return sludge for reconditioning as a more dilute sludge reacts far more readily than a denser sludge in the sludge reconditioning unit.

Partial Treatment.—Up to the middle of October, 1938, except when Unit 2 was used as a separate unit, all the sludge from Unit 1 was passed through Unit 2 either alone, for secondary treatment, or with varying quantities of tank effluent. In this period total volume passed through Unit 2 varied from 2.0 m.g. to 6.5 m.g./day and varied from straight sludge to a mixture of 2.0 m.g. of sludge with 4.5 m.g. of tank effluent. Based on oxygen absorbed figures only, the percentage purification varied from 71.2 to 80.5 per cent.

From the middle of Oct. to Dec., 1938, only a portion of the sludge from Unit 1 was admitted to Unit 2, the remainder being by-passed to meet the effluent from Unit 2. The author has worked out a factor called the work done factor which takes into account the volume treated. This factor is used to evaluate the work done by Unit 2. The factor is [(Oxygen absorbed of tank effluent) — (Oxygen absorbed of settled pretreated liquor)] × (Volume treated in hundreds of thousand gallons). This figure is believed to be far more valuable than per cent purification. Similar factors are obtained for albuminoid ammonia and B.O.D. Results for Unit 2 during December, 1938, show the application of this factor:

	Ox. Absorbed from N/80 $KMnO_4$ in 4 Hrs. @ 80° F.	Albuminoid Nitrogen as Ammonia	B.O.D.
Per Cent Purification	56.3	12.0	63.3
Work Done Factor	132.9	3.94	653.0

Since the Kessener units have been in use, monthly percentage purification, based on oxygen absorbed have been raised approximately 10 per cent. Power used for sludge reconditioning was very low. During Dec., 1938, 76,787,000 gal. of sludge were treated in Unit 1 and power used was 164.8 units per m.g., or about 6.83 k.w.h. per m.g. or 9.15 h.p. per m.g.

Unit 2 was used under storm conditions to give partial treatment to the storm water in excess of three times the dry-weather flow. Improvement made by this treatment compared to plain settling is shown in the tabulation.

Date	Ox. Absorbed in Four Hrs., Parts per 100,000		Volume Treated, Gallons	
	Effluent from Storm Tanks	No. 2 Kessener Unit Effluent Partial Treatment	Storm Tanks	No. 2 Kessener Unit
Nov. 28	2.74	1.24	1,445,000	5,112,000
Dec. 1	3.52	1.40	3,418,000	5,164,000
Dec. 5	3.09	0.99	3,787,000	4,900,000
Dec. 15	4.73	2.32	754,000	4,990,000
Dec. 29	5.68	1.40	3,173,000	4,988,000

The conclusion reached is that the Kessener Brush is extremely efficient and economical and in the case of Stockport has improved the quality of the final effluent.

F. E. DeMartini

SEWAGE DISPOSAL SCHEMES

Considerations Affecting Their Economic Design and Efficiency

By Lawrence J. Ball

Borough Surveyor's Office, Eastbourne

Presented at Meeting of the Southern District of the Institution of Municipal and County Engineers, Reading, Jan. 24, 1939. Excerpts in *The Surveyor*, **95**, 257–58, (Feb. 10, 1939)

The majority of present-day sewage purification schemes are either for augmenting the capacity of an existing works or for its replacement on a larger scale. Rapid urban development has overtaxed many plants of recent design, and the extent to which an existing works can be retained is a primary consideration in any proposed scheme on account of the opposition that would probably be encountered in the scrapping of an old plant while its loan period is unexpired. The selection of the plant site is often dependent upon the line and grade of existing outfalls and general development features, and also upon the sometimes prohibitive cost of long outfall extensions, extra pumping, etc., to a more desirable site.

Improvement of Existing Works.—In this connection it is necessary to determine if all the plant units are equally overtaxed, and thus decide if additional works are required in parallel with the old works, or whether the old works can be improved. The open or closed septic tanks used in the older plants might be altered to serve as sedimentation tanks and this, as the records show, would increase the capacity of the bacteria beds about 15 per cent. The deficiency in existing sedimentation tanks could be overcome by additional tanks in parallel or series, mechanical flocculation, and for a works serving over 50,000 population, a mechanically scraped primary unit might economically reduce hand-cleaning costs. Contact beds, depending upon their lay-out and design, might be used as rectangular percolating filters with traveling distributors, as storm-water tanks, or without removing the old medium as sludge-drying beds. The efficiency of percolating filters might be increased by double filtration but this would entail additional expenditure on pumping and structural additions. Where the sewage flow would not increase or change in character appreciably the beds might be assisted by adding a partial activated sludge process. The improvement of properly designed humus tanks would be difficult, and usually new tanks or additional capacity in parallel would be necessary.

Design of New Works.—The choice of site is usually limited, and the following factors should be considered:

(*a*) Proximity to:
  1. The point where purified effluent might be discharged.
  2. Electricity, water services, and roads.
(*b*) Ground levels.
(*c*) Subsoils.
(*d*) Subsoil water level.

The probability that industrial wastes may be added by new industries should be considered. In selecting the method of treatment, the size of site, ground configuration and ground-water level, the quantity and strength of sewage, the sewerage system, the degree of purification required, seasonal fluctuation of flow, cost of electrical power, and probably future development should be considered. The use of power-operated mechanical devices should be limited by the lowest dry-weather flows of medium strength sewage as follows:

Detritus elevators ("combined" sewerage system only)	¾ m.g.d.
Screen rakes (single unit, hand-cleaned by-pass)	½ m.g.d.
Screen rakes (multiple all-mechanical units)	1½ m.g.d.
Screenings macerator	2 m.g.d.
Primary sedimentation sludge scraper (circular tank)	½ m.g.d.
Secondary sedimentation sludge scraper and scum skimmer (rectangular tank)	3 m.g.d.
Humus scraper (floor and sides, circular tank)	½ m.g.d.

Normally the cost of collecting gas for generating power was uneconomic for works treating less than 2,500,000 (Imp.) gal. daily dry-weather flow from 75,000 persons, but this depended upon the cost of power from the mains. The degree of purification required is due principally to locality and to the condition of the stream, etc., receiving the effluent. When the effluent is discharged into the tidal reaches of some rivers plain sedimentation and barging sludge to sea may suffice, while in other cases an effluent with a five-day B.O.D. not exceeding 20 p.p.m. may be required. Large seasonal variations in population may determine the most economic type of treatment, such as activated sludge treatment where low capital costs are more important than short period high-operation costs.

In the construction of percolating filters attention should be given to double filtration and dilution methods, and also to the most suitable media for use in the beds. The following table was presented to show the comparative values of filter media:

Desirable Property	Material				
	Granite	Porphyry	Clinker	Slag	Metallurgical Coke
Durable	Very good	Best	Unreliable	Free lime may slake. Known to have burst walls of bed	Proved satisfactory over 20 years
Low conductivity	Not very satisfactory	Not very satisfactory	Fair	Fair	Best
High surface area/volume ratio	Good	Good	Best	Very good	Best
Rough texture for film adhesion	Good	Fair	Variable	Fair	Best
High per cent voids in bulk	40 per cent	37 per cent	Variable	Ave. 45 per cent	Best 48 per cent
Low sp. gr.	1 cu. yd./ton	1 cu. yd./ton	Intermediate variable	Intermediate variable	Best 2¼ cu. yd./ton
No tendency to pack in use	Slight, encouraging ponding	As for granite	Appreciable if disintegration takes place	Appreciable if disintegration takes place	Best, negligible
Cost/cu. yd.	6s to 15s, according to locality	6s to 15s, according to locality	Varies with quality and locality	Varies with quality and locality	15s to 17s 6d according to locality

The following conditions should be sought in works employing sludge digestion without gas collection:

(1) Avoidance of short circuiting.
(2) Good dewatering arrangements at varying levels.
(3) Minimum surface/volume ratio including tank surfaces, for heat conservation.
(4) Interchangeability of tanks.
(5) Adaptability for gas collection at a later date.

Short circuiting may be eliminated by two-stage digestion when tank feeds are tangential at mid-depth. A series of downward opening penstocks, or tappins at various levels may suffice for dewatering. Minimum surface/volume ratio is approached by circular tanks, with vertical sides approximately two-thirds diameter in height and 30 deg. bottom slopes.

Insufficient sludge bed capacity may cause acute difficulties for works managers in inclement weather, but the use of roughly tamped concrete floors at slight falls would greatly improve drainage at reasonable cost.

Large areas of grass on lawns and steep banks took a disproportionately large share of maintenance costs. The planting of shrubs such as *cotoneaster horizontalis* created a pleasing effect and only required occasional weeding.

S. G. MONROE

ANNUAL REPORT ON THE SEWAGE PURIFICATION WORKS FOR THE YEAR ENDED MAY 31, 1938, CORPORATION OF GLASGOW, SCOTLAND

By Alexander Hunter

Pamphlet (20 pages)

During the year an average of 16¼ m.g.d. of sewage from the eastern purification area was treated by chemical precipitation with alum and lime at the Dalmarnock Works. Forty-one per cent of this was given further treatment on percolating biological filters. The total production of sludge (176,379 tons) was forced through a 9-in. cast iron main by compressed air to the Shieldhall sewage works (distance 6¼ miles) at a cost of 1.30 d. per ton. An experimental Simplex activated sludge plant of ½ m.g.d. capacity was in continuous operation during the year. A new enclosed aeration filter (18 ft. deep by 52 ft. in diameter to treat ½ m.g.d. of sewage was constructed and put into commission.

At the Dalmuir Works an average of 38½ m.g.d. of sewage from the western purification area was treated by chemical precipitation. The sludge (318,817 tons) from the precipitation tanks was conveyed a distance of 31 miles to sea by the two sludge steamers at a cost of 6.73 d. per ton.

The Shieldhall works treated an average of 17 m.g.d. of sewage from the southern disposal area and produced a total of 440,786 tons of sludge. This sludge was disposed of at sea at a cost of 5.6 d. per ton. The old sludge pressing house is being demolished and the plant and machinery disposed of. Arrangements are being completed for the installation of a Mieder mechanical sludge scraper, suitable for removing sludge from five precipitation tanks each 300 ft. long by 60 ft. wide. Plans are being prepared for a new detritus chamber and contracts for mechanical screening gear and other equipment have been let.

Tables of analyses of the sewage and effluent at each of the above works are appended, also a table showing the quantities of chemicals used during the years. The percentage reduction in albuminoid ammonia obtained at these works varied from 31.9 to 42.3 per cent at Shieldhall and Dalmuir to 61.5 to 72.5 per cent at Dalmarnock. The corresponding percentage reductions of the oxygen absorbed were 27.5 to 31.3 for Shieldhall and Dalmuir and 46.3 to 57.5 at Dalmarnock.

C. C. Ruchhoft

DETROIT PRIMARY TREATMENT PLANT NEARS COMPLETION

By Arthur B. Morrill

Municipal Sanitation, **10**, 32–34 (Jan., 1939)

Since the International Joint Commission started a survey of Canadian boundary waters in 1915, the pollution of the Detroit River has been a local and international problem. Financial, legal and administrative difficulties have long delayed construction of the Detroit sewage treatment plant. This delay of the principal offender has led to general retardation in action by other communities along the Detroit and St. Clair rivers. A sewage treatment plant for Detroit is now nearing completion and will be put in operation some time during 1939. In point of population and sewage flow provided for, this plant will be one of the world's largest. Because of its large size and the fact that no secondary treatment is required, the cost will be unusually low. The site is large enough to provide primary treatment for 4,000,000 people. The sedimentation tanks and most other features are designed for a population of 2,400,000 in the year 1950.

Eventually there will be 8 pumps with a maximum capacity of 2,000 c.f.s., the same as the interceptors and outlet conduit. As some of the pumps will be needed only in times of storm, no reserve pumping capacity is to be provided. Under maximum flows, two pumps will handle 300 c.f.s., four 250 c.f.s. and two 200 c.f.s. All of the pumps

are to have constant speed synchronous motors, variable speed pumps not being needed because of long storage in the intercepting sewers.

After leaving the pumps the sewage will pass through a battery of eight grit chambers, each receiving the discharge of one pump. The velocity of flow will be close to one foot per second under all conditions of operation. The screens are to be mechanically cleaned. Immediately before each grit chamber is a mechanically cleaned bar rack with ¾ in. spaces. Screenings and rakings are to be carried on belt conveyors to incinerators.

The sewage will next be treated in eight sedimentation tanks of unusual size, each with a capacity of 52.5 m.g.d. with a nominal detention period of 1.5 hours. At the maximum rate of flow in 1950, this time will be reduced to 51 minutes. The tanks are unusual in that they are covered with a low concrete slab roof and divided by continuous concrete walls into separate flow channels 16 ft. wide, 14 ft. deep and 272 ft. long. There are seven sewage channels in each tank. Provision is made for chlorination before or after sedimentation.

The outlet conduit from the plant has been completed and filled with water. A temporary clay blanket, placed on the river bottom to safeguard construction of the conduit, has now to be removed. Of the 6,000 ft. of conduit, 400 ft. is under the river and the remainder under land.

H. W. Streeter

THE DETROIT SEWAGE TREATMENT PLANT

By Clarence W. Hubbell

Civil Engineering, 8, 667–669 (Oct., 1938)

The Detroit Sewage Treatment Project includes intercepting sewers, a pumping station, racks, grit chambers, plain sedimentation tanks, sludge digestion, and elutriation tanks, sludge filters, incinerators for raw and digested sludge, screenings and grit. Provision is also made for chlorination of the effluent.

The intercepting sewers are designed and built to serve an ultimate population of 4,000,000 and have a maximum capacity of 2,000 cu. ft. per second. The average per capita flow is estimated at 175 gal. per day. A surge basin of 14,400 cu. ft. capacity is provided for protection of structures and equipment in the interceptors and plant, and to prevent street flooding through manholes.

A circular pumping station with outside diameter of 113 ft. will be equipped with eight motor-driven centrifugal pumps. The average lift is about 30 feet. The present plant installation will serve a population of 2,400,000 and an average flow of 420 m.g.d. as of 1950.

The rack screens, with net openings of ¾ in., are mechanically cleaned. There are eight grit chambers, each 160 ft. long by 16 ft. deep. The width varies with the capacity of pump served, to give an average velocity of 1 ft. per second. Screenings are to be ground and returned to the sewer. Grit is to be incinerated. An average removal of 21 cu. yd. of screenings and 62 cu. yd. of grit per day is expected.

The sedimentation tanks are 272 ft. 8 in. long, 16 ft. wide, and 14 ft. deep, and will provide an average detention period of 1½ hours. There are eight units of seven tanks each, and each is covered with low slab, sod-covered roofs. The effluent from these tanks will be treated with an estimated average of 10 p.p.m. of chlorine, and then discharged into the Detroit River, through an 18 ft. diameter tunnel which terminates in a submerged crib located about 400 ft. beyond the harbor line. The crib is about 40 ft. deep and in swift flowing waters.

Under the present plan of operation the raw sludge from the sedimentation tanks will be conditioned with lime and ferric chloride, dewatered by vacuum filters and incinerated. The estimated average production of sludge in 1950 will be 240 tons of dry solids per day. The quantity of sludge cake to be incinerated is estimated at 922 tons

per day, which includes about 36.5 tons of residual solids from conditioning chemicals. The moisture content of the cake is estimated at 70 per cent. The production of ash will be 125 tons per day. Twelve vacuum filters of the blow-back scraper type are provided, each with 500 sq. ft. of effective filtering area. Four incinerator units of the circular multiple-hearth type, with a total capacity of 1,200 tons per day, will be installed. This incinerator capacity is deemed adequate for a population of 2,400,000 on the basis of incinerating raw sludge, and for an ultimate population of 4,000,000 on the basis of incinerating digested sludge.

The original project called for eight digestion tanks, each 105 ft. in diameter and 42 ft. in depth, and also an elutriation plant prior to dewatering and incineration. Because of lack of funds, only one digestion tank and one-eighth of the elutriation plant are to be built at this time.

The revised estimated cost of the entire project as of September 1, 1938, is $22,635,000, of which $19,030,000 is for construction and the remainder for preliminary costs, land and engineering.

S. G. MONROE

DETERMINATION OF DISSOLVED OXYGEN

Rideal Stewart and Alsterberg Modifications of the Winkler Method

BY C. C. RUCHHOFT, W. ALLAN MOORE, AND O. R. PLACAK

Ind. Eng. Chem., 10 (1938)

The samples of water used for the comparative determination of dissolved oxygen by these two methods were collected along the Scioto River from Columbus to a point approximately 115 miles south. The samples were collected simultaneously in two standard 300 ml. bottles contained in a standard sampling apparatus. The bottles were tightly stoppered and transported to the laboratory at Chillicothe, Ohio, where the dissolved oxygen was determined. The maximum elapsed time between the collection of the samples and their analysis was three hours.

The Rideal-Stewart modification of the Winkler procedure as given in Standard Methods was used on one set of samples while the following azide modification was used on the other:

"To the sample of water in a standard 300-ml. bottle, 0.7 ml. of concentrated sulfuric acid is added, followed by 0.8 ml. of a 2.0 per cent aqueous solution of sodium azide. The bottle is stoppered, the contents are mixed by shaking, and the bottle is allowed to stand for 10 minutes. One milliliter of manganous sulfate solution and 3.0 ml. of alkaline potassium iodide solution are next added and the sample is shaken for 20 seconds. Following this the precipitate is allowed to settle and the sample is acidified with 2.0 ml. of concentrated sulfuric acid. The liberated iodine on a volume of solution equivalent to 200 ml. of the original sample is titrated immediately with 0.025 N sodium thiosulfate, using starch indicator."

In order to be sure that the azide-nitrite reaction has been completed the 10-minute period of standing should be used before the Winkler reagents are added. When high nitrite concentrations are encountered (4:0 p.p.m. or above) the manganous hydroxide floc has a tendency to rise due to the entrainment of free nitrogen. This may be eliminated by shaking the bottle vigorously a second time, whereupon the nitrogen is disengaged.

Four hundred and eleven pairs of samples were analyzed by these two methods. The results obtained show that the azide method gives on an average a slightly higher dissolved oxygen content than the Rideal Stewart modification. The comparative figures are given in the following table:

COMPARISON OF DISSOLVED OXYGEN RESULTS ON 411 SCIOTO RIVER SAMPLES
(Sodium Azide and Rideal Stewart Modifications of the Winkler Method)

Sampling Station	No. of Samples	Mean Dissolved Oxygen		
		Sodium Azide Modification, P.p.m.	Rideal Stewart Modification, P.p.m.	Deviation, P.p.m.
Columbus	38	7.50	7.26	0.24
Shadeville	39	3.16*	2.94*	0.22
Commercial Point	38	3.11†	2.91†	0.20
South Bloomfield	42	2.42	2.23	0.19
Red Bridge	38	3.47	3.34	0.13
Circleville	38	4.53	4.34	0.19
Penn. R. R. Bridge	38	4.44	4.10	0.34
Kellenberger	23	4.51	4.23	0.27
Chillicothe	13	6.54	6.20	0.34
Kilgore	10	6.36	6.10	0.26
Higby	13	6.44	6.16	0.28
Waverly	10	7.32	7.04	0.28
Lucasville	10	7.60	7.37	0.27
Paint Creek	22	7.38	7.10	0.28
Miscellaneous	39	6.93	6.63	0.30

* Thirteen samples were 0.0 by each method and were not included in this average.
† Six samples were 0.0 by each method and were not included in this average.

A comparison of the 5-day B.O.D. at the various stations with the dissolved oxygen results obtained by the two methods does not suggest any correlation between the mean 5-day B.O.D. at any station and the mean deviation of the dissolved oxygen as determined by the two methods.

The azide method is shown to be very effective in the destruction of nitrites; in only one case of the 411 determinations did the starch-iodide color return. The slightly lower results obtained by the Rideal-Stewart modification are ascribed to the oxidation of organic matter during the permanganate treatment. The azide method is one step shorter than the Rideal Stewart modification in that it is not necessary to destroy the excess sodium azide added, whereas the excess of permanganate must be destroyed with oxalate before the Winkler reagents are added, which step introduces other sources of error.

W. A. MOORE

EXPERIMENTS ON TREATMENT OF CANNERY WASTES

Anon. Public Works, **70**, 10 (Jan., 1939)

Experiments were made by the Wisconsin Canners Association, the National Canners Association and the Wisconsin State Board of Health during the summer of 1938, on the treatment of pea, corn, beet, tomato and carrot canning wastes. All experiments were made on screened wastes, as experience has indicated efficient screening is the first and most important step in handling wastes of this type. Screening was done by means of a rotary screen covered with 40-mesh wire and equipped with an efficient rotary spray for washing. Further treatment was by either chemical treatment or by biological treatment comprising repeated passes of the waste through a high rate trickling filter filled with a ceramic filtering media. The experimental work indicated that satisfactory chemical treatment was lower in first cost, but higher in operating cost than biological

treatment on trickling filters. The filters, however, required a preliminary conditioning period of about ten days before effective results were obtained. This "ripening" period is a material handicap to the use of a biological filter in the treatment of cannery wastes although under special circumstances the necessary growth on the filter media could be built up by the use of some other waste prior to the canning season.

The objective of chemical treatment is to obtain an effluent with a pH not less than 9.6, giving a sludge that dries quickly on the beds, usually cracking within 12 hours and becoming removable within four days. The pH of the fresh raw wastes closely approximates that of the water used, but decreases on storage, particularly in hot weather, necessitating prompt treatment and disposal of the effluents.

Work on pea cannery waste showed that the previously developed chemical treatment with lime and ferrous sulfate gave the best results. Substitution of alum for ferrous sulfate gave nearly equal results. Silage juice from the pea vine stacks cannot be satisfactorily treated by the use of chemicals and the best method of disposal is by land irrigation.

Beet canning waste is of a dark red color containing considerable dissolved organic matter and fine organic solids, together with sand and dirt. Practically all of the common coagulants were tried, but the most effective chemical treatment consisted of the application of 10 lb. lime and 4 lb. ferrous sulfate per thousand gallons yielding an orange or amber effluent free from suspended solids, and a reduction in B.O.D. of 59 per cent. Lime alone as a coagulant will give the characteristic color change and is responsible for about 80 per cent of the reduction in B.O.D. but the addition of the ferrous sulfate increases the settling rate and gives greater clarification. Laboratory experiments using lime and zinc chloride gave a reduction in B.O.D. averaging 89 per cent and a water white effluent but the dosages necessary are comparatively high in cost.

The application of 8 to 10 lb. lime and 9 to 12 lb. ferrous sulfate per thousand gallons of corn canning waste produced a B.O.D. reduction of about 60 per cent and a water-white effluent. It is important to add the ferrous sulfate in several steps, about three-quarters of the necessary amount being added in the first dose and the rest in small batches with continuous agitation. Effective treatment is attained when the green floc becomes large and curd-like and settles rapidly.

Sedimentation of tomato waste results in marked clarification. Further treatment can be best obtained by dosages of 4 lb. lime and 1 lb. alum per thousand gallons resulting in a B.O.D. reduction of 50 per cent, but the precipitate is light and settles slowly.

Carrot canning wastes can be satisfactorily treated by precipitation with 5 lb. lime and 1 lb. ferrous sulfate or with 8 lb. lime alone per thousand gallons. Sufficient agitation should be provided to produce a medium size floc which will settle, leaving a light yellow effluent, with a reduction in oxygen demand of about 75 per cent.

Biological treatment of beet, corn and tomato wastes was obtained by repeatedly passing them through a trickling filter at the rate of 458 gal. per sq. ft. per day (20 m.g.a.d.). Six passes of beet waste accomplished a B.O.D. reduction of about 60 per cent; six passes of corn waste, a reduction of 75 per cent; and three passes of tomato waste a reduction of 65 per cent, with a clear, colorless effluent. Uniform dosing of the filter was essential.

R. S. SMITH

THE PRESENT TREND IN SEWAGE PURIFICATION

BY H. T. CALVERT

J. Royal Sanitary Institute, 59, 547–558 (1939)

The aim of sewage purification is to purify sewage to such a degree that in its later discharge it will not endanger health, create a nuisance, pollute rivers or bathing beaches, nor cause damages or hardships to users of river water below the point where the effluent is discharged.

In England in 1876, sewage was treated on sewage farms, by land filtration or by precipitation and chemical processes. From 1898 to 1915 these types of treatment had almost disappeared in favor of the newer artificial biological methods, such as contact beds and later percolating filters.

The evolution of sewage treatment has been most rapid during the past 20 to 30 years. Purification is now accomplished in several stages: the removal of suspended solids by sedimentation, the conversion of the non-settleable solids into settleable flocs by coagulation or flocculation, and the oxidation of organic solids in solution. Chlorine is now being used for odor control, delaying septic action, cleansing percolating filters and sterilizing effluents.

The paper is discussed by many authorities.

Mr. H. C. Whitehead discusses bacteria beds. Corbett in 1892 showed that a percolating filter bed could treat 350 gal. per cu. yd. per day. In 1921, O'Shaughnessy used the activated sludge process prior to treatment on percolating filters. Chemical treatment is now understood more fully, and has advantages for effecting increased clarification. Two unorthodox methods of operation of trickling filters are now being used; one, alternate filtration using two filters in series, and second, enclosed filtration with forced ventilation. O'Shaughnessy, and more recently the Water Pollution Research Board, in experimental work on milk wastes, have found it advantageous to dilute strong liquors with effluent prior to filtration.

Mr. Arthur J. Martin said we may expect renewed competition between activated sludge and trickling filters as a result of recent work. He also hoped more study would be given to use of wet sludge on the land because of the content of humus, phosphates and substances of which the soil stood in need.

Mr. H. D. Manning referred to the need for a central research station and urged that generous government grants should be made available for the purpose.

Mr. A. P. I. Cotterrell mentioned his visit to large treatment works in America. He suggested that for England possibly smaller sectional works with regional control might be just as efficient.

Mr. F. C. Temple suggested that sewage sludge and town refuse be composted to form humus so that the land which was formerly nourished with sewage could be fertilized by the humus.

Dr. S. H. Jenkins stated that whatever treatment was chosen for purifying sewage, micro-organisms played the most important rôle. Studies showed that in the upper part of a percolating filter, where purification was most effective, biological activity was greatest.

Dr. A. Parker summed up the status of various types of sewage treatment. He reviewed the research projects of the Water Pollution Research Board, which have included experiment station studies of the disposal of beet sugar wastes, dairy wastes, and recently large-scale tests of the alternate-filter scheme of Dr. Jenkins, for which the Birmingham Board had provided four percolating filters, each with an area of 1,200 square yards. Other work had been carried on in various laboratories. It was hoped that a central research laboratory would be established within the next two or three years.

Sir Albert Howard drew attention to the inadequacy of chemical analysis in estimating the value of organic manures. In some cases a unit of nitrogen in organic combination sold for almost three times the market price of a unit of nitrogen in the form of sulfate of ammonia. The true value of the material could be determined only by application to land.

Prof. W. W. Jameson, Dr. G. McGowan, Mr. Wm. Butler and Mr. David Ronald also spoke.

H. GLADYS SWOPE

TREATMENT AND DISPOSAL OF SEWAGE AND TRADE WASTE WATERS AND PREVENTION OF RIVER POLLUTION

International Union of Local Authorities, Glasgow, September, 1938

By A. Parker

Asst. Director of Water Pollution Research, British Government Dept. of Scientific and Industrial Research

Dr. Parker reviews the history, legal status, methods of treatment and disposal of sewage, and methods of treatment of trade wastes. He discusses joint boards and co-operation and research. He confines himself almost entirely to the work in Great Britain.

In Great Britain, the average quantity of domestic sewage is 20 to 30 gallons per capita per day, with a strength of 300 to 400 p.p.m. 5-day B.O.D. at 18 deg. C.

Disposal of raw sewage by dilution is allowed if the ratio of raw sewage to the water is 1:500 volumes. With a dilution of 300 to 500 volumes the suspended solids discharged must not exceed 150 p.p.m.; if dilution is 150 to 300 volumes, suspended solids should not be greater than 60 p.p.m. As a general standard when dilution is low, complete biological treatment of the sewage is required so that the B.O.D. will not exceed 20 p.p.m. and the suspended matter, 30 p.p.m.

Horizontal continuous-flow sedimentation tanks are usually built for a capacity of not less than one-half the daily dry weather flow. Septic tanks usually have a minimum capacity of 1.25 times the daily dry weather flow.

Chemical precipitation is not being used to any great extent in England at the present time. One interesting use of chemical treatment, however, is that at Bradford, where the sewage contains industrial soaps. Sulfuric acid is added to the sewage to separate the grease or fat from the soaps and causes coagulation of the finely-divided and colloidal solids in the sewage. The sludge is then treated for recovery of the grease.

Chlorine and other chemicals are used for odor control, prevention of excessive growths in filters, and for delaying septic action of the sewage.

There are three principal methods of treatment of sewage on land: surface or broad irrigation, sub-surface irrigation, and filtration. A table showing the classes of soils, methods of working, and area required in acres per million gallons per day is given.

Biological oxidation in filters may be either carried out in contact beds or percolating filters. For average strength, settled sewage in Great Britain, a contact bed is capable of treating 35 to 50 gallons per day per cubic yard. A percolating filter can treat 70 to 80 gallons per day per cubic yard.

Dr. Parker describes briefly five means of diffusing air in the activated sludge process: (*a*) porous plates, (*b*) mechanical surface aeration, (*c*) revolving brushes, (*d*) revolving paddles and (*e*) perforated pipes.

Average domestic sewage in Great Britain requires an aeration period of from 5 to 15 hours in order to produce a B.O.D. not greater than 20 p.p.m. in the final effluent. At the Birmingham, Tame, and Rea District Drainage Board, the settled sewage liquor is partially treated by activated sludge using an aeration period of two hours. The return sludge is reaerated in a separate tank. The partially aerated effluent is purified in high-rate percolating filters.

The problem of sludge disposal has not been satisfactorily solved. In Great Britain, 10 to 20 tons of sludge (one ton, dry basis) is obtained per million gallons of average domestic sewage treated in primary sedimentation tanks. A few plants are digesting sludge in separate tanks and using the gas for power and heating.

Methods of treating trade waste waters: All effort should be made within the industry itself to use its waste products, thereby reducing the load on the sewers and in many cases making a saving to the industry in the recovery of by-products. Trade wastes may be divided into three groups: (1) those requiring the removal of suspended matter only, (2) those which require removal of suspended matter, but also contain polluting matter in solution, and (3) those containing polluting substances in colloidal dispersion or in solution. The wastes in the latter two cases may require complete treatment but can usually be purified at the sewage treatment plant unless the volume is too

great or the wastes contain substances detrimental to the sewers or the sewage treatment process.

Dr. Parker states that greater efficiency and economy can be obtained by having joint sewerage schemes similar to the Birmingham, Tame and Rea District Drainage Board and the West Middlesex District.

Research, too, should be better co-ordinated. Most of the work is now being done by individuals at sewage plants, universities and other organizations but without any attempt to co-ordinate their various problems. England has only one central organization—the Water Pollution Research Board, under the Government Department of Scientific and Industrial Research.

H. GLADYS SWOPE

(Note: The above pamphlet may be obtained in the U. S. A. at the Public Administration Service, 1313 E. 60th St., Chicago, Illinois. Price, 60 cents).

"SEWAGE PURIFICATION"

This is a new British publication, edited by Mr. B. Wyand in London. It is a monthly journal, published by the Technical Publishing Company, Ltd., 8 Breams Bldg., London E C 4. The price is 12 shillings per year. The technical editor is Mr. Reginald C. Shaw, who formerly worked under Mr. Garner, Chief Inspector, West Riding of Yorkshire Rivers Board, a past president of the Institute of Sewage Purification and one of the contributors to "Modern Sewage Disposal."

The first issue contains messages of welcome from Dr. Calvert, Mr. J. B. Croll, Mr. J. H. Garner, Mr. Charles H. Ball and others; original articles, translations from *Gesundheits-Ingenieur*, and papers presented at the Institute of Sewage Purification meetings. Two articles from the new journal are abstracted herewith.

Although this journal apparently has the support of the Institute of Sewage Purification and other English technical societies, it is not the official publication of any society but a commercial undertaking.

A REVIEW OF PROGRESS IN SEWAGE TREATMENT

BY W. D. HAWORTH

Sewage Purification, 1, 8–13 (1939)

Mr. Haworth describes developments under the following headings: area occupied by works, screens and detritus tanks, sedimentation tanks, sludge digestion, comparison of the Imhoff tank with separate units, bio-aeration processes, filters, sludge drying, and various chemical processes.

The use of filters for treating sewage has greatly reduced the area required, as compared with land treatment, and the new aeration processes have reduced the area required still further.

For the small works no great progress is shown in screen design for those hand raked. For mechanically operated screens several designs are available.

The most popular sedimentation tank in England, the Dortmund inverted-pyramid settling tank, with central baffled inlet and hydraulic sludging arrangement, is still eminently satisfactory.

Separate digestion of sludge is employed at most works, the digestion tanks being equipped with stirring devices and peripheral heating coils to maintain a temperature of 80 deg. F. The capacity provided is usually 3 cu. ft. per capita. A diagram is shown and a description given of the compact design of settlement and sludge digestion tanks at the Eastleigh works.

The biological filter or bacteria bed is generally found in use for a part, at least, of the settling tank effluent even though aeration processes are used.

Most sludge is dried on beds but where sludge pressing is used it is found advantageous to add lime to the sludge at the time of pressing.

TRADE EFFLUENTS. I. PAST AND PRESENT LEGISLATION

By John Hurley

Sewage Purification, **1**, 16–19 (1939)

Past Legislation. The Public Health Act of 1875 was an endeavor to care for industrial wastes but the statutory obligations of Local Authorities concerning such wastes were so vaguely defined and so modified by provisos as to be easily avoided.

Another law, which was a step in advance, was the Rivers Pollution Prevention Act of 1876. This too, was weakened by numerous provisos so that the Third Report (1903) of the 1898 Royal Commission on Sewage Disposal expressed the opinion that it should be the duty of the Local Authority to provide sewers for trade wastes. In the Commission's ninth report (1915) they suggest the right of the Local Authorities to make a charge for carrying the trade effluents in sewers.

In 1927, a Joint Advisory Committee on River Pollution was set up to relieve the chaotic position regarding trade wastes. The views of this Committee were published in their second report (1930). The main conclusion was that the Local Sanitary Authorities should be under general obligation to take and dispose of the trade effluents of their districts. The Local Authority would have the right to require treatment of the trade effluent prior to disposal into the sewer, if necessary.

Present Legislation. The Public Health (Drainage of Trade Premises) Act, 1937, is of outstanding importance. The Local Authority may make by-laws regarding the discharge of trade wastes. He may be required to do so by the Minister of Health. Such by-laws may cover: (1) time of discharge of trade waste to sewer, (2) exclusion of condensing water, (3) elimination of any constituent of the waste which might alone or in combination with other wastes be detrimental to the sewer or sewage treatment plant or to a stream into which it may later be discharged; (4) the amount of waste which may be discharged at any one time, (5) temperature and pH of the waste, (6) charge for carrying such waste into the sewer, regard being had both to the volume and composition of the waste; (7) provision and maintenance of a man-hole so that samples of waste may be obtained and (8) meters for measuring the volume of the waste.

Before any trade waste is discharged to a sewer the Local Authority must be notified and the industry must give the following information regarding such waste: (1) nature or composition, (2) maximum quantity discharged in any one day and (3) highest rate of discharge. Consent of the Local Authority is necessary before discharge of waste into the sewer.

In Section 7 of the Act, the Local Authority may enter into agreements with owners or renters of trade premises for the reception and disposal of the waste by the Local Authority. The agreement may provide for the construction of a treatment plant by the Local Authority and for the repayment by the owner or renter of the premises of a whole or part of this expense to the Local Authority.

As a whole the Act is workable but it is unfair in one respect. If an Authority has refused to accept a waste but is now compelled to take it, the Authority can set up by-laws to govern this discharge and may charge for its services. On the other hand if an Authority has accepted a waste, it exercises very little control over the discharge of this waste. Section 12 of the Act, however, gives the Minister of Health the power to amend local Acts so as to bring them into conformity with the new Act.

H. Gladys Swope

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Library Assn. of Portland, 801 S.W. 10th Ave., Portland, Ore.
Oregon State Agricultural College, Library, Corvallis, Ore.
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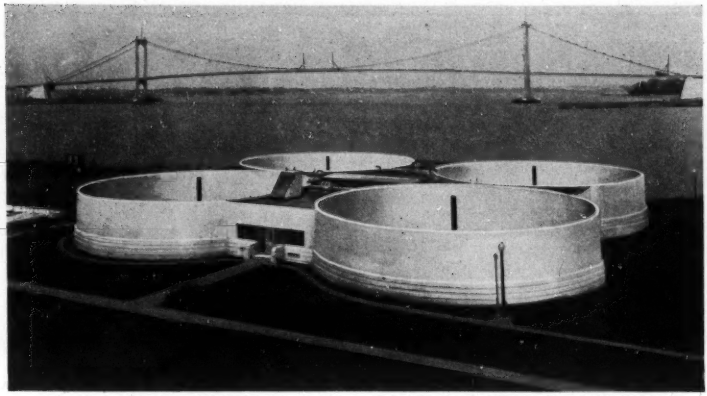
Quaraishi, G. S., 251/1 Ramswami Qrs., Karachi, India.

Webster, K. C., 19 Hoofd St., Boksburg, Transvaal, S. Africa.



Floating Covers are in lowest position as plant was not in operation when photograph was made.

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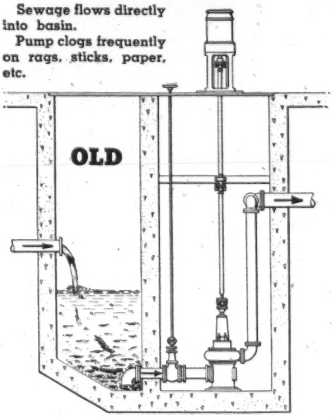

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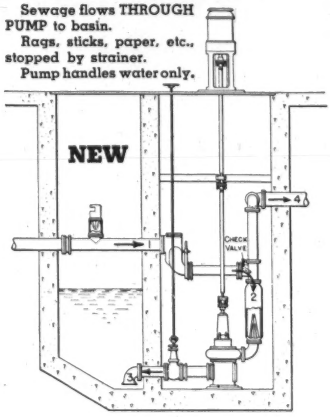

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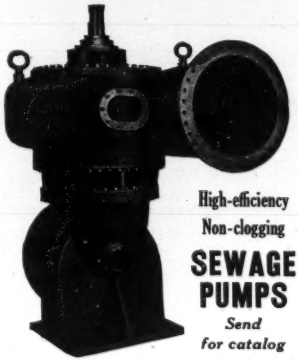

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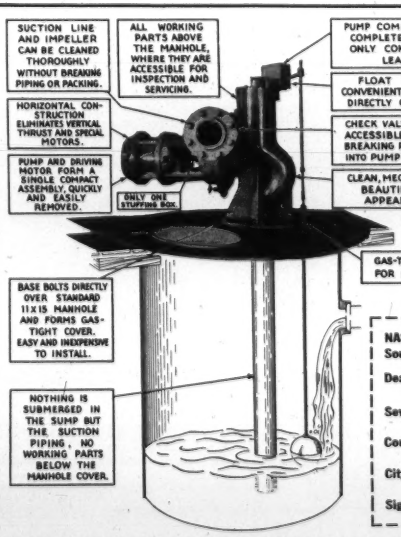
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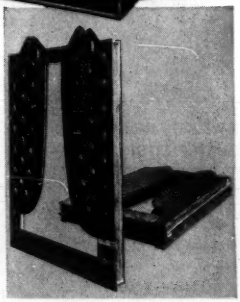

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